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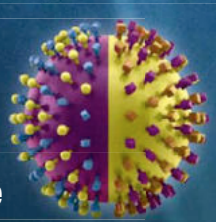

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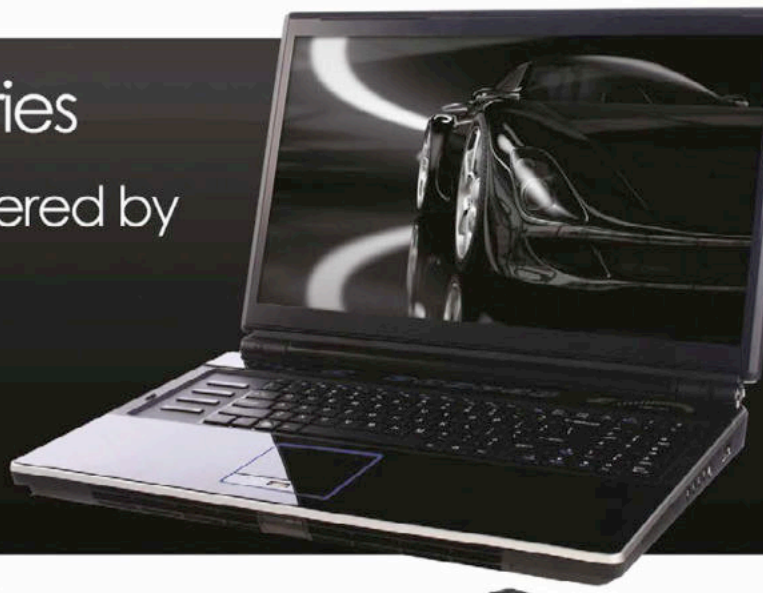

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WELCOME TO FOCUS

"ONE DAY, IT will have to be officially admitted that what we have christened reality is an even greater illusion than the world of dreams." So said the surrealist painter Salvador Dali, and he could be right. Last century, Einstein gave us a whole new perspective on the Universe with relativity. Now, experiments are in progress that could once again turn our thinking on its head. Among them is the quest to find out if the entire Universe is in fact a hologram. It sounds crazy but there's some serious science behind the theories. Prepare to have your mind blown on p34.

Einstein apart, who was the greatest physicist of the 20th Century? I would argue Richard Feynman, a Nobel laureate and an inspiration to millions. Twenty-five years after his death, we asked John Gribbin to explore his scientific legacy (p56).

Last year I was lucky enough to visit the incredible ruins of Pompeii. Now, the British Museum is mounting an exhibition of its treasures, so we're taking a timely look at the secrets the archaeological site still might serve up.

Finally, if you've got the sniffles this winter, don't despair! A cure for the flu could be just around the corner – although, sadly, too late for this year. Until next issue.

Graham

Graham Southorn, Editor

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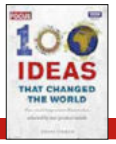

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APPEARING IN THIS ISSUE...

Marcus Chown

The author of popular science titles such as *We Need To Talk About Kelvin* and *The Never-Ending Days Of Being Dead* is a former NASA cosmologist. This makes him the ideal person to look at efforts to discover whether the Universe is a hologram.

John Gribbin

A visiting fellow at the University of Sussex, John is also a renowned science author. His many books include *Richard Feynman: A Life In Science*, which he wrote with his wife Mary. Here he looks at Feynman's most inspirational ideas.

Liz Kalaugher

The editor of online news service Environmental Research Web, Liz has a PhD in materials science. She reports on a robotic submarine that is mapping the Antarctic ice shelf to study the effects of climate change.

Mike Pitts

The editor of *British Archaeology* magazine, Mike is an active archaeologist who has directed digs at both Avebury and Stonehenge. Here he considers how science will shed new light on Pompeii.

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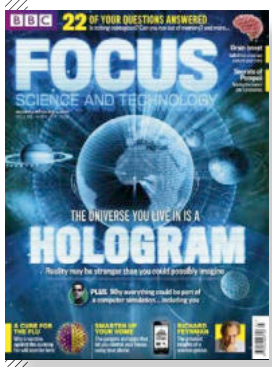

ON THE COVER

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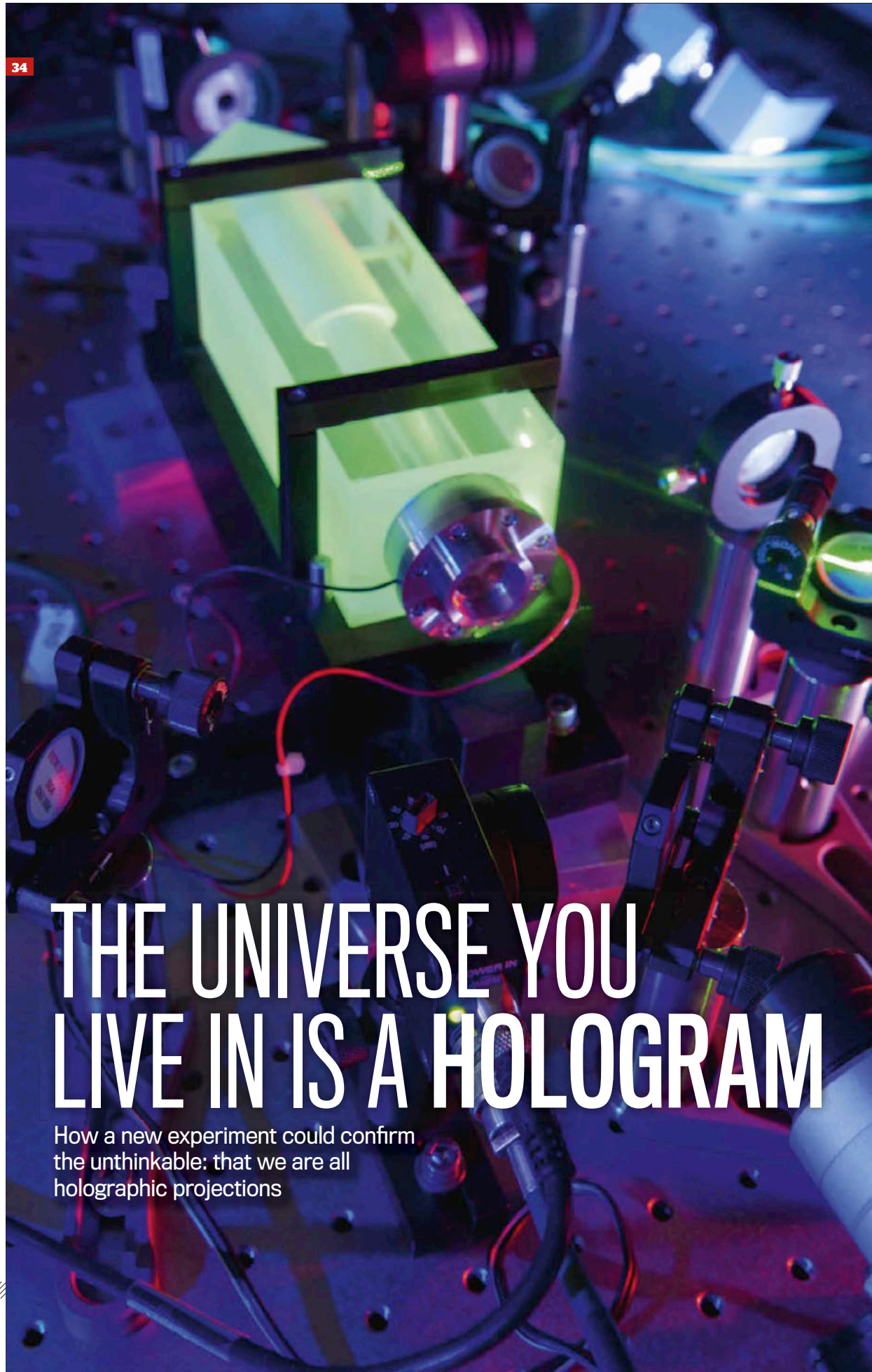

THE UNIVERSE YOU LIVE IN IS A HOLOGRAM

How a new experiment could confirm the unthinkable: that we are all holographic projections

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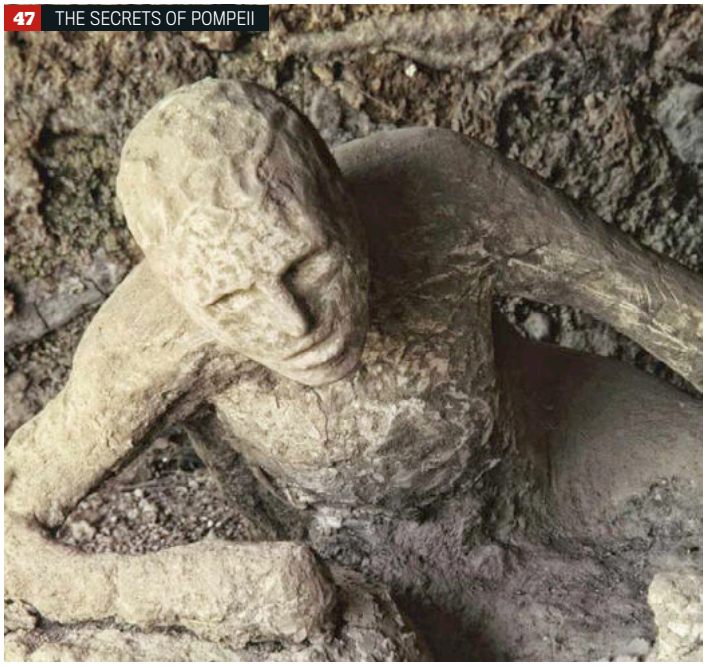

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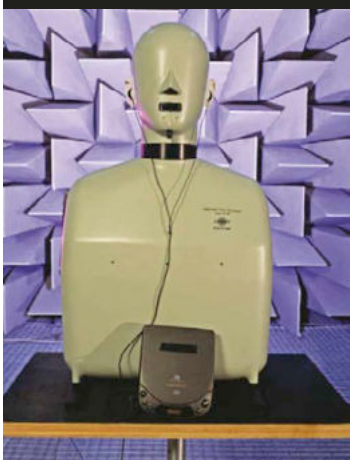

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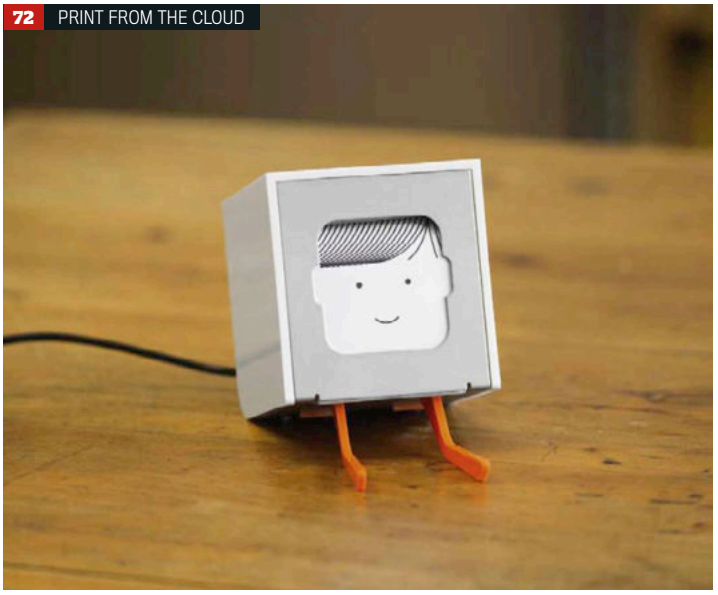

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Awe-inspiring images from the world of science

MegaPixel

Blowing bubbles

A CYLINDER OF bubbles rises inside a huge tank at the University of Texas. This 'bubble curtain' is being tested as a means to block out the sound of offshore drilling, so the chatter of whales and dolphins isn't drowned out.

The idea is simple – the bubble curtain surrounds the source of noise, perhaps a drill, stopping many of the sound waves. "An acoustic wave in air or water is a fluctuation of pressure," says Associate Professor Preston Wilson, who is involved with the research. "If the noise source is surrounded by soft bubbles, the sound wave squeezes the bubbles rather than the water." This removes the sound wave's energy, stopping it from reaching any nearby marine mammals.

Although free-floating bubbles have already been used for underwater noise reduction, tests like this have shown that it's better to encapsulate them in plastic. This is because generating them makes a noise in itself, but it's also hard to maintain large free-floating bubbles, which are more effective at subduing the low frequency sound of drilling.

PHOTO: ERICH SCHLEGEL

MegaPixel

Orange orbs

THESE FIERY DOMES were spotted in La Paloma mine in western Spain and are composed of the mineral cacoxenite. Despite its beauty, the mineral's name comes from the Greek words for 'bad' and 'guest' because its phosphorous content was thought to reduce the quality of iron smelted from the associated ore. Cacoxenite's vibrant colouration means it is used in jewellery.

"If you cut these structures down the middle, you'd see long, fibre-like crystals," says Andrew Bloodworth, Head of Science for Minerals and Waste at the British Geological Survey. "These grow radially outwards from the mineral below, which is what gives the cacoxenite this bulbous shape. The bright orange colour probably comes from the iron contained in the crystal lattice."

Cacoxenite is usually found on iron ore deposits, formed over thousands of years as rain and water vapour react with the rock. As well as iron, it contains phosphorous, oxygen, hydrogen and aluminium.

PHOTO: HONORIO COCERA-LA PARRA/NIKON SMALL WORLD

MegaPixel

Airship reborn

IN A VAST hangar in southern California sits a 21st Century airship. But it's a far cry from similar aircraft that cruised the skies in the early 1900s.

While airships have traditionally required ballast tanks often filled with water to control their altitude, the Aeroscraft, developed by Aeros, employs a very different system. When the pilot wants the craft to descend, helium inside a central gas cell is compressed and air drawn in from the outside, reducing buoyancy. Gaining altitude is simply a matter of releasing compressed helium. An outer skin of helium surrounding the central chamber maintains the craft's shape.

With a clever system that allows the Aeroscraft to load and unload itself, Igor Pasternak, the founder of Aeros, says he's built an aircraft that can operate in the most undeveloped regions: "If you are building a factory in Africa where there are no roads, for example, this vehicle becomes the infrastructure."

While the 79m-long prototype airship pictured here is put through its paces this year, work will continue on a full-scale version that will be twice the length.

PHOTO: REX

REPLY

Your opinions on science, technology and our magazine

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MESSAGE OF THE MONTH

He knew there was a wood there somewhere, but for some reason he just couldn't see it

Tall tales

December's Q&A answer to 'Why are the tallest trees on Earth not even taller?' (p102) combines height information with trunk width, implying that the tallest trees have the widest trunks. It then goes from confusion to error in attributing height limitations to disease and disaster.

The trees with the widest trunks are *Sequoiadendron giganteum*, found in California. These are also the largest by mass. The tallest trees – with trunks much narrower than *S. giganteum* – are *Sequoia sempervirens*, also found in California. The assertion that disease and disaster are the height-limiting issues is just wrong. While it does take time and luck to get very tall, height is restricted to how high water can be transported to leaves. Studies suggest the theoretical maximum is only a little higher than the tallest *Sequoia sempervirens*.

Kenneth Koutz, California

Luis Villazon replies:

I didn't mean to imply that the tallest trees are also the widest. My point was that for a given tree, growing taller also requires growing wider, to support the extra weight. This means each additional metre of height requires the tree to grow more wood than the last, and so growth slows down over time. Having looked into the theoretical limit to transporting water up the trunk, I agree that this is probably the fundamental constraint on height.

Write in and win!

The writer of next issue's Message Of The Month will win the Roku LT worth £49.99. Plug it into your TV and the Roku LT streams over 300 channels, including Netflix, BBC iPlayer and Now TV, direct to your screen. www.roku.com/uk

Going nuclear

Your article on asteroid mining (November, p68) got me thinking. Spending 10 years moving an asteroid is too long. My suggestion is to attach several missiles to the asteroid, each fitted with several nukes. It should be possible to slow it enough to impact on the Moon. Further in the future, a large mining ship could be built in space that could process the asteroids in the belt itself.

John Sims, Derby

The problem would be that explosives might break some asteroids apart, making something of a mess in space. –Ed

Waste not, want not

In his 'Inside Science' column (January, p27), writing about how insulating homes may not lead to energy savings, Robert Matthews comments: "Humans have an annoying habit of changing their behaviour according to circumstances – and not always in a good way."

I remember Arthur C Clarke once also complaining about this habit of humans to be wasteful, warning that if advances in technology ever led to cheap or free energy, the consequences for the environment would be disastrous. At work I once poured away a drink from a vending machine because I'd pressed the wrong button by mistake; my manager pointed out that I wouldn't have done that if I'd had to pay for it. The same is true of energy, but on a global scale.

Alan Thomas, Shepperton

Flying blind

Your Q&A reply to 'How do aeroplanes fly upside down?' (January, p83) was not quite correct. There's a widespread misconception that the aeroplane wing gets its main lift from the Bernoulli Effect of its profile, so it looks to the layman as though it ought not to be able to fly upside down. But though this does provide some lift, the primary source of lift for all subsonic aircraft is actually the same as that which keeps skiers on top of snow: the support mechanisms, the skis or wings, continually deflect downwards, mainly from their undersides, a mass of snow or air equal to the weight of the

PHOTO: SUPERSTOCK

person or aircraft. They do not require a cambered shape to do this.

This is why balsa wood model aircraft with a completely flat wing can fly, and why skis work even though they are flat and their upper sides are not immersed in their medium.
Roger Britton

Thanks to Roger and to Bernard Hawkins, who supplied very detailed explanations of why planes can fly upside down. –Ed

Market madness

Robert Matthews's article on Extreme Value Theory (January, p49) is interesting, but there are other aspects to the stock markets that concern me. I was an engineer who specialised in dynamics and control. A few years ago, I concluded that stock markets were unstable, with huge spikes and no damping. Further investigation revealed that more than 70 per cent of trades are algorithmic. Not only that, but markets are fitting higher speed fibre-optic links to save a few milliseconds.

I tracked down a senior figure in the Bank of England and to my astonishment he replied, agreeing with my opinion. He did say that they were trying to do something about it, but it is surely a subject worthy of some attention.
Jim Stark

Lukewarm Pi

As a young coder, aged 15, I sympathise with Stephen Wolfram's aim in January's edition of *Focus*. Nowadays there are many simple ways to learn to program, such as Python – a simple and extremely powerful language. This is an important part of the Raspberry Pi. A downside of Python is that it does not leave much scope for learning how a computer works. When this is turned to a human language interface, computer science will become even more distant. You will no longer be teaching children how to code – you will be teaching them how to talk to a computer, which will not equip them with the skills they need to innovate with code. Children will learn to code better by using original computer languages.
Harry Tanner, Hampshire


The Raspberry Pi is a learning ground for programmers

What we don't know

I enjoy your magazine but the answers within 'Questions at the frontiers' [the subscriber bonus feature] seem rather wordy. The responders seem to use a lot of words to say "We don't know". I would suggest an approach that says, "We don't know – but..." and then discusses what *is* known.

It's OK to admit to being human and say "We don't know".
Ralph Rahn, Arizona

Absolutely! The whole point of our 'Questions at the frontiers' features is to look at areas of science right up to the limit where our current understanding breaks down. Hence the inconclusive answers. –Ed

YOUR COMMENTS ON OUR FORUM

Joseph Jefferson It seems highly plausible that within a few years all cars, buses, trucks etc will be controlled by computers making vast numbers of people unemployed (to which a friend of mine replied 'surely the goal is full unemployment?')

M Paul Lloyd Autonomous vehicles are already finding their way around the streets of some towns on an experimental basis and removing the human element from driving would appeal to the safety conscious amongst us. I could spend the time finishing the crossword or checking Twitter. The big issue here is what would happen to all the lorry drivers?

Shadowwolf We would unarguably have safer roads with automated systems and they would also likely be more fuel efficient and people wouldn't breach regulations like bad lane changes or speed limits. Like people before them, [professional] drivers would see a career shift. Well over a century ago, time-consuming, arduous tasks performed by poorly paid people were transformed over the course of the Industrial Revolution.

Join in the the discussion at www.sciencefocus.com/forum

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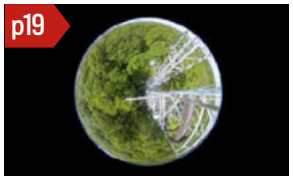

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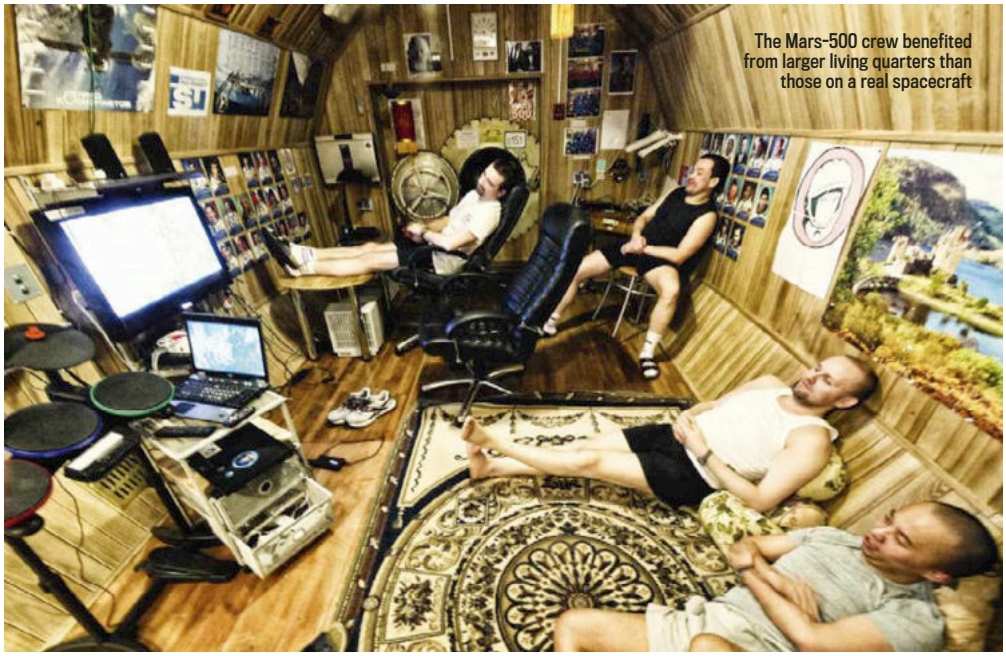
THE BIG STORY

Getting inside the mind of an astronaut

520-day isolation experiment examines the psychological impact of long-term space travel

PHOTO: ESA



The Mars-500 crew benefited from larger living quarters than those on a real spacecraft

ASTRONAUTS HEADED FOR Mars would have to battle with sleep deprivation and an inability to focus on tasks, according to the first investigation into the psychological effects of long-term space travel. The scientists behind the Mars-500 experiment, who have just released their findings, say mimicking conditions on Earth inside a spacecraft would be key to ensuring a successful long-term mission.

With NASA planning to send astronauts to Mars by the 2030s, the effects of long-term space travel are a hot topic. Yet only four people have spent more than a year in space, providing little data on the mental and bodily effects this may have. So the Russian Academy of Sciences, working with the European and Chinese space agencies, built a mock spacecraft inside the Institute of Bio-Medical Problems in Moscow to test the effects of long periods of isolation, and six male volunteers from Russia, France, Italy and China spent 520 days cooped up inside the facility.

While some of the conditions inside – such as the wood-clad walls and leather office chairs – were not exactly spaceship-like, the experiment was designed to mimic a real mission as closely as possible, with a communication delay with 'ground control' and no natural light. Each subject wore a watch-like 'actigraph' that recorded their movements, and twice a week they carried out a 'psychomotor vigilance task' that measured reaction times. The tests showed that the crew members became more sedentary and four of them suffered disturbed sleep, although the crew tended to sleep more overall. The performance of some crew members in tasks faded due to chronic sleep deprivation.

There were huge differences between the volunteers in the amount they slept and their activity levels. "We need to be able to tell who's going to be affected, to select the right crew. We also need to help them cope on a real mission to Mars," says Prof Mathias Basner of the University of Pennsylvania. Having similar light and dark cycles to those on Earth would help, he added.

As well as the primary isolation experiment, Mars-500 has also involved several 'satellite experiments' connected to long-term space travel. In the Gamma Breeze project, over 20 rhesus monkeys were exposed to the same radiation levels as would be encountered by astronauts on a Mars mission.

KELLY OAKES

ANALYSIS

David Green

Lecturer in Aerospace Physiology, King's College London

"THE MARS-500 mission was an attempt to simulate aspects of a mission to Mars such as the isolation, monotony and limited resources. But the problem was that the experiment was held in Moscow. If something went wrong, the astronauts could have got out safely. They also lived in a 550m^3 volume, which is far in excess of how much room there'd be on a spacecraft travelling to Mars.

You can't simulate looking out of a window and seeing Earth disappear behind you. One of the key psychological issues on a Mars mission will be dislocation. Astronauts who've been to the Moon all say how disconcerting it was to get further and further from the Earth. On a trip to Mars, at some point the Earth is going to be the size of a pin, and then you'll lose sight of it. Who knows what that will do to someone?

Microgravity and radiation also weren't simulated in the main Mars-500 study. As we leave the Van Allen belt – the two layers of charged particles that surround the Earth – the protection the Earth affords us is no longer there. In addition, muscle loss, bone loss and reduction in cardiovascular function are all problems that we associate with being in microgravity for a long period of time, so the effects of these need to be investigated."

TIMELINE

How our understanding of the effects of long-term space travel has emerged

1970

Apollo 13 crew pass over the far side of the Moon, 254km above its surface. This puts them further from Earth than any human before or since.

1988

Russian cosmonaut Valeri Polyakov, on his first trip into space, stays onboard the Mir space station for 240 days before returning to Earth.

1995

Cosmonaut Valeri Polyakov spends 437 days on the Mir space station, setting the record for the longest continuous period away from Earth.

2007

The end of the first stage of the Mars-500 experiment, in which a crew of six Russians, five men and one woman spend just 15 days in isolation.

2009

The second stage of Mars-500, lasting 105 days and involving six male crew members, is completed. A final stage is then able to commence in 2010.

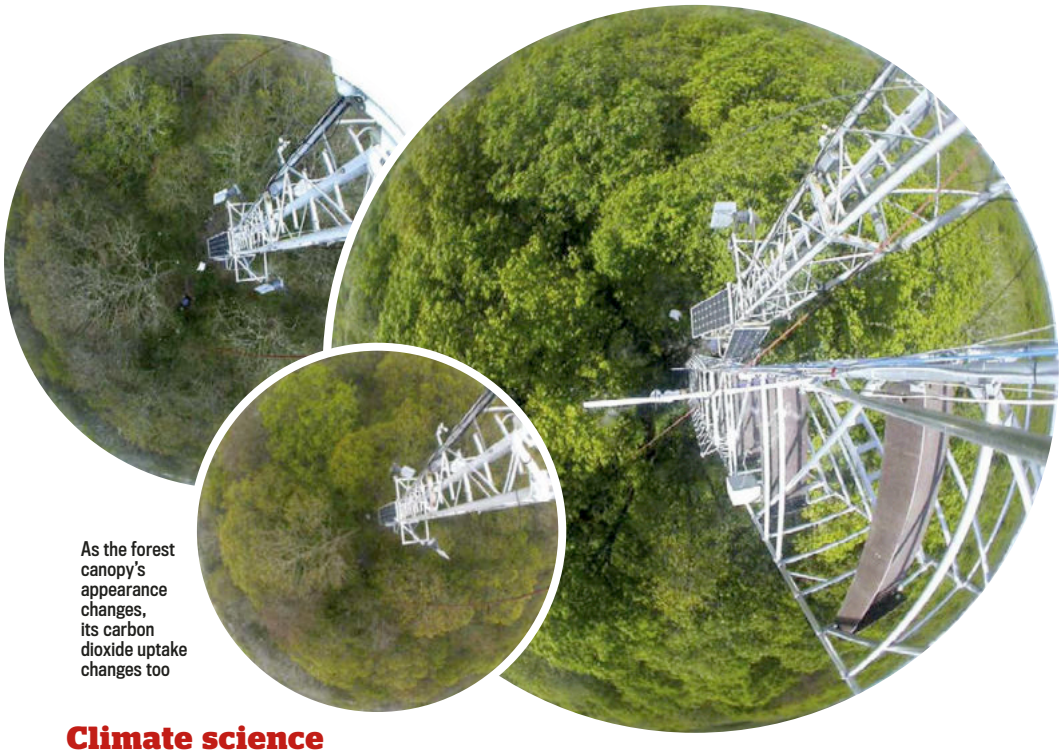
2012

The results of the final phase of Mars-500 are published. Several crew members show disturbed sleep patterns and impaired concentration.

WHAT DO YOU THINK?

Would you spend 520 days in space? Tell us at facebook.com/sciencefocus

PHOTO: ESA, NASA, SCIENCE PHOTO LIBRARY, SPACEX



As the forest canopy's appearance changes, its carbon dioxide uptake changes too

Climate science

Cameras capture climate-cooling efforts of trees

DIGITAL CAMERAS COULD become an important tool for monitoring the growing threat of climate change, now that ecologists have found a way of using them to measure how much carbon dioxide forests are taking up.

Forests are a vital 'sink' for the carbon released when fossil fuels are burned. A global network of tower-mounted carbon dioxide (CO_2) sensors called FLUXNET currently monitors this carbon uptake by forests. These sensors are expensive, and cover only a small fraction of the Earth's surface – but it now appears that taking a series of photos of a forest will do the same job.

University of Edinburgh ecologists fixed two cameras on Alice Holt forest in Hampshire and took a photo every half hour during daylight for two years, giving them 38,000 snaps in total. They then used image-processing software to analyse changes in the forest canopy. As expected, the strength of the green signal in the images jumped up during the spring season as the leaves came out. Of all the parameters measured, the forest canopy's colour showed the strongest agreement with measured carbon uptake.

The Edinburgh ecologists say that spring is arriving earlier each year, but it's not known how these longer growing seasons affect the amount of carbon absorbed by trees. A global network of forest-monitoring digital cameras is now being established that will provide some insights, but there's still a lot to learn.

"It's important for us to replicate the same method in other forests," says Toshie Mizunuma, a PhD student at Edinburgh. "In Alice Holt we studied an oak forest, but other trees such as maples and ash trees have different colours. So we're trying to study forests of different species."

Visit bit.ly/VWcabM to watch a video about the research.

JAMES LLOYD

1 MINUTE EXPERT
Memory molecule

What's that?
It's a protein that has been held up as *the* molecule that allows memories to form. The idea, based on research on rats, was that blocking this enzyme, kinase M-ζ or PKM-ζ, could wipe out old memories, while adding it could strengthen old ones.

Why is it in the news?
Neuroscientists at Baltimore's Johns Hopkins University deleted two genes, one for PKM-ζ and another for a related protein called PKC-ζ, in mice embryos. Researchers at the University of California, San Francisco, created similar mice. In both cases, the mice had perfectly normal memories.

So what does this mean?
Todd Sacktor at New York's SUNY Downstate Medical Center, who did the earliest research on PKM-ζ, says a different protein may have stepped into the breach as the mice grew. But the Johns Hopkins team also created mice whose PKM-ζ gene could be deleted by giving them a specific drug. This meant they could stop PKM-ζ production when the mice were adults, and they still had a normal memory. The Johns Hopkins team say this doesn't mean PKM-ζ isn't involved in memory – it just may not play as pivotal role as was thought.

WHO'S IN THE NEWS?
Elon Musk

Co-founder of PayPal and founder of SpaceX

What did he say?
He revealed his vision for an 'oasis' settlement on Mars that would be home to 80,000 pioneers. Speaking at the Royal Aeronautical Society in London, he said he'd been waiting 10 years to reveal his vision. "Then it seemed ridiculous because there were no rockets, no infrastructure and NASA was the only game in town – and it had no schedule for exploring Mars. But with my work, and many others working in the private sector, the mission is coming closer to reality."

How does he see this colony developing?
Musk said he would initially start with a group of 10 pioneers who would build a greenhouse in which to grow crops. Over time, the colony would be extended to tens of thousands of people. "Too few, and the gene and culture pool dries up," Musk said. "Too many and you risk civil war."

How can you become a Martian?
Musk hopes that one day the general public will be able to buy a ticket to Mars for $500,000.

PATENTLY OBVIOUS

Inventions and discoveries that will change the world with James Lloyd

Celebrity face spotter

FANCY JOINING THE paparazzi? There may soon be an app for that. A new patent application from Apple describes how future iDevices will be able to instantly recognise any celebrities in snaps you have taken.

After a photo has been shot, the system generates a 'faceprint' – a series of numbers that describe a person's face – for each of the people in the image. The software then trawls through a database to look for any matching celebrity faceprints. The idea is that this automated process could identify a movie star wandering by in the background when the user hasn't spotted them.

Apple says the system could be used to recognise 'iconic images' – presumably things like the Taj Mahal and the Eiffel Tower – in your snaps, as well as the occasional passing pop star.

With Google also pursuing an automatic celebrity recognition system (patent application number US 20110116690), it looks like A-listers will soon have to wear increasingly elaborate disguises to remain incognito.

Patent application number: US 20120314962

Shocking handcuffs

A NEW BREED OF handcuffs has been developed that are, quite literally, shocking. These cuffs can restrain a subject by administering powerful jolts via electrodes placed against their skin.

Scottsdale Inventions in Arizona, the company looking for a patent, says its handcuffs could be kitted out with sensors such as an accelerometer, a microphone and a 'location sensing device', so shocks could be triggered if a detainee approaches a restricted area, makes a threatening movement or even raises their voice. As well as handcuffs, the technology could be built into items such as ankle cuffs or straitjackets, and it can also inject substances into the suspect, to provide medication or to debilitate them. But the handcuffs have prompted much negative comment on blogs, with many ethical and safety concerns raised.

Patent application number: US 20120298119

Pilot soothing system

BOEING HAS OUTLINED a system that can monitor a pilot's emotional state. Temperature, perspiration and heart rate monitors are built into the pilot's flight suit, while a headset inside his/her helmet takes EEG readings. A high heart rate and beta brain waves above 18Hz would indicate high stress levels, so the system might declutter the pilot's in-flight display or present tasks in order of importance.

Patent application number: UK 2491984

PHOTO: JOURNAL OF VISUALISED EXPERIMENTS ILLUSTRATOR: ROBIN BOYDEN

THEY DID WHAT?!

Bees trained to stick out their tongues

What?

Scientists at Bielefeld University in Germany have trained honeybees to stick out their tongues when their antennae touch something.

How did they do this?

They applied a conditioning technique made famous by Ivan Pavlov. Strapping the bees into tiny harnesses, they gave them a taste of sugar water when their antennae brushed a textured surface. Soon, the bees would stick out their tongues whenever their antennae came into contact with the right surface.

Why did they do it?

The researchers, led by professor of biological cybernetics Dr Volker Durr, hope to use this 'proboscis extension response' to gain an insight into how bees use their antennae to identify what's around them, a process that is not yet properly understood.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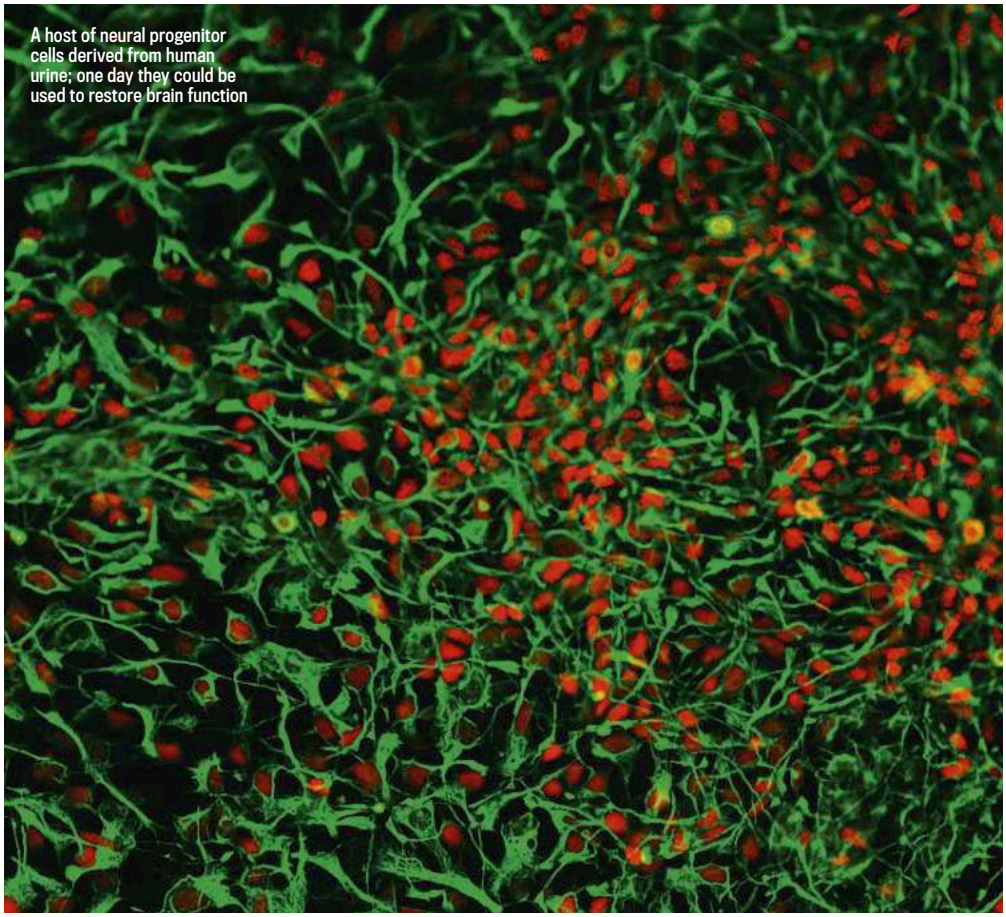


A host of neural progenitor cells derived from human urine; one day they could be used to restore brain function

Neuroscience

Cells in your urine could restore your brain power

CELLS EXTRACTED FROM urine have been transformed into brain cells, potentially providing a new way to treat degenerative conditions such as Alzheimer's disease. Chinese researchers have found a new way to tweak the DNA of kidney cells so they take on a radically new role.

Stem cells – cells that can convert into any kind in the body – offer great promise for treating neurodegenerative diseases, replacing brain cells that have been damaged or destroyed. But stem cells taken from embryos pose ethical concerns, while cells taken from adults and reprogrammed into stem cells are more likely to develop genetic mutations.

In this new research, biologists at several Chinese institutions isolated cells from the kidneys in the urine of three donors. Instead of using a virus to reprogramme the cells – the technique usually employed with cells taken from adults – they used a small circular piece of bacterial DNA. This replicates in the cell's cytoplasm, the gel-like substance within a cell membrane. While viruses integrate the reprogramming genes into the cell's chromosomes – increasing the risk of mutations – the bacterial DNA works its magic from the cytoplasm.

These reprogrammed cells formed neural progenitors, cells that can form different types of nerve cell. They were then driven to produce mature brain cells that could generate nervous impulses.

But what about the 'yuk factor' of using cells from a patient's urine to restore their brain? Professor Duanqing Pei at the Chinese Academy of Sciences who is involved with the study, isn't concerned. "Urine cells are sterile and easy to obtain," he says. It's this availability of raw material cells compared with using blood samples and biopsies, and the reduced risk of mutation, that make this approach so attractive.

ZOE CORMIER

PHOTO: PAN GUANGJIN, PHIL TORRES

DIGITAL WORLD

Science on the web

ASTERANK

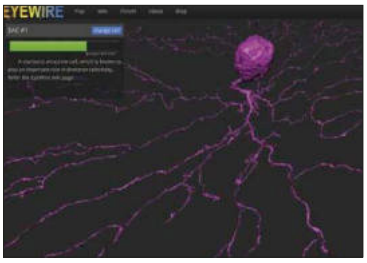
www.asterank.com/3d/

This simulation shows over 580,000 of the asteroids in the Solar System... and estimates the value of the minerals they contain in cold hard cash. This is a site that is bound to leave dollar signs in the eyes of extra-terrestrially inclined entrepreneurs.

EYEWIRE

www.eyewire.org

This is a game for adults who used to love colouring books. You colour in images of nerve cells in the retina by clicking a mouse to help map the connections, enabling MIT neuroscientists to understand how it all works. It may not be the slickest site, but what EyeWire lacks in flashiness it makes up for in sheer addictiveness.



Colour-in the nerve cells at EyeWire to further our understanding of vision

CHROME WEB LAB

www.chromeweblab.com

Interact with physical installations at the Science Museum in London from the comfort of your own home – it's where cyberspace meets meatspace. You can play a robotic band at the museum, or take a picture with your webcam and have it doodled in sand.

ETERNA

http://eterna.cmu.edu/web/

EteRNA is a game that asks you to arrange coloured discs into chains. But it's much more than that: the chains are virtual molecules of ribonucleic acid, or RNA, and after the initial tutorials, you design *real* molecules. Every two weeks, Stanford University scientists synthesise the best designs.

KELLY OAKES

GRAPHIC SCIENCE

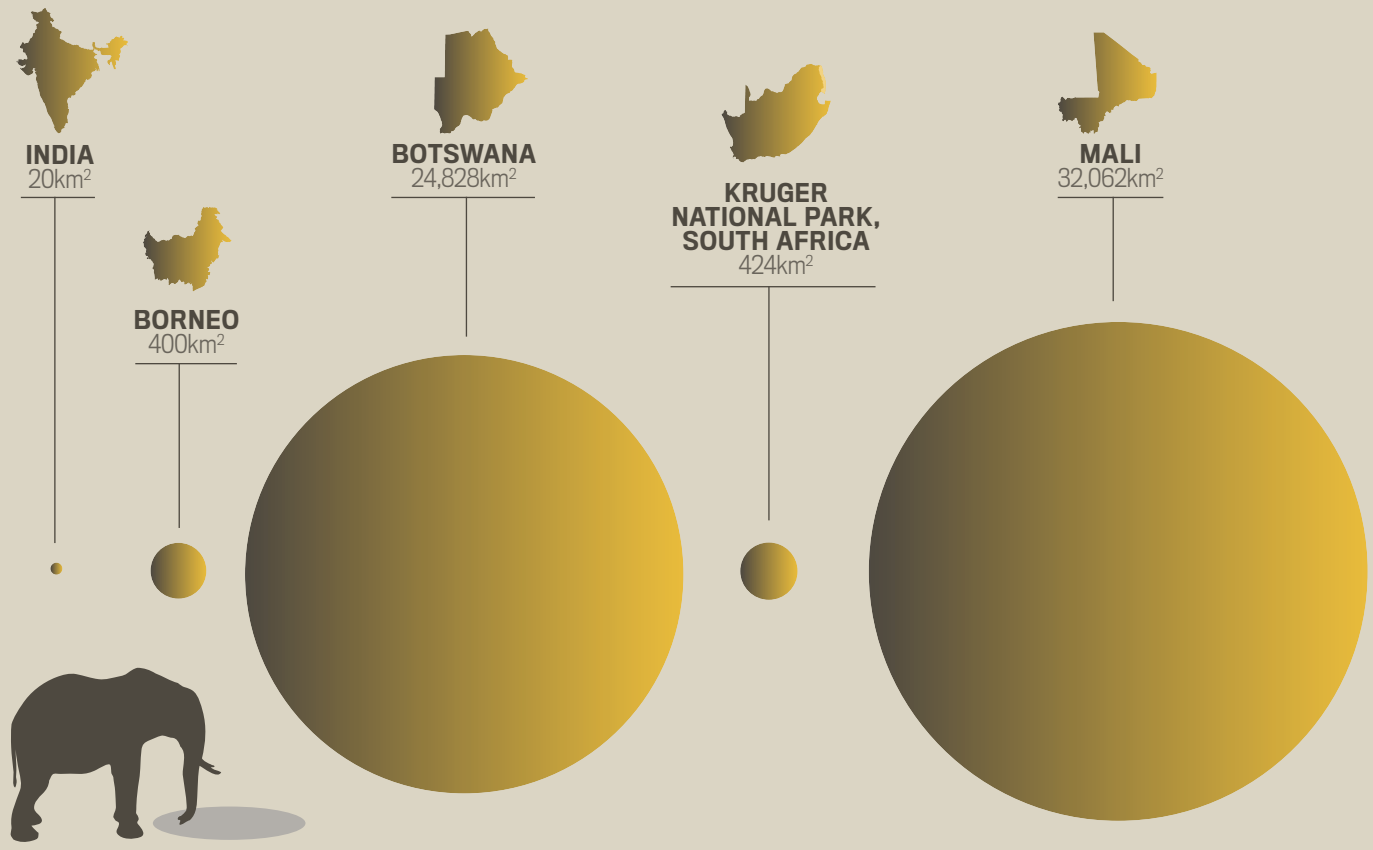
Seeing research differently

EPIC ELEPHANT JOURNEYS TRACKED

A HARDY GROUP of elephants living in the Sahara Desert has been found to roam over an area larger than Wales in search of food and water each year. Nine Gourma elephants that live in northern Mali were fitted with GPS collars by researchers from Oxford University and Canada's University of British Colombia, and tracked for two years. Below, the area that the Malian elephants roam each year can be compared with the areas covered by other groups of elephants from countries across the world.

> The environment in Mali is extremely harsh, and elephants have a narrow window during the year when the rains fall and vegetation is lush. They need to move fast and far to keep up with the pasture and raid pools from which they can drink.
> **Iain Douglas-Hamilton, Oxford University and Save The Elephants**

Areas covered by elephants annually



NEWS IN BRIEF

A tangled web...

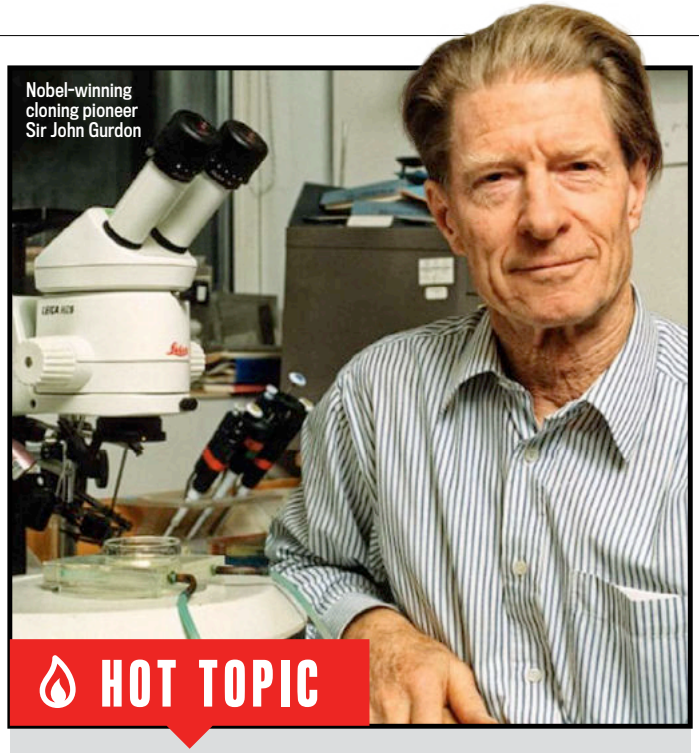
It looks like a spider, it moves like a spider, but this creepy crawly is actually made of leaves, dead insects and other debris. It's the handiwork of a far smaller arachnid, pictured just above its creation. The small spider, recently discovered in the Peruvian Amazon, is thought to build its masterpiece as a decoy for would-be predators.

Titanic moon river

NASA's Cassini spacecraft has spotted what looks like a miniature version of the Nile on Saturn's largest moon, Titan. Stretching more than 320km (200 miles) from source to sea, the unnamed river appears as a dark stain on the moon's surface, indicating that it's filled with liquid hydrocarbons. It's the largest river system ever found outside our own planet.

Lake drilling delay

It's likely to be at least three years before the British team hoping to drill through 3km of Antarctic ice into Lake Ellsworth are able to try again. The team called off their drilling mission because of concerns they weren't making enough progress. Their equipment will now need to be sent back to the UK, modified, then reinstalled.


Nobel-winning cloning pioneer Sir John Gurdon

HOT TOPIC

Should human cloning be allowed?

HUMAN CLONES COULD be born within the next 50 years, says Sir John Gurdon, the British scientist who won a Nobel prize for his work on cloning frogs in the 1950s and 60s. Speaking on BBC Radio 4's *The Life Scientific*, he said that at the time of his frog experiments, he predicted that a mammal would be cloned within 50 years, and that the same timescale could apply to human cloning today. His original prediction about mammal cloning came to pass in 1996 with the birth of the first cloned sheep, Dolly.

It's been suggested that cloned humans could provide replacement organs to siblings who are ill, or even replace children who have died. But the ethics of this remain highly controversial. Gurdon, however, believes human cloning may yet meet with public approval. "I take the view that anything you can do to relieve suffering or improve human health will usually be widely accepted," he said.

WHAT DO YOU THINK?
Let us know your opinions at **twitter.com/sciencefocus** using the hashtag **#hottopic**, and **facebook.com/sciencefocus**

Your Tweets and Facebook posts

Noah Sprent: *I'm not sure true cloning can really exist: we are products of our environment. A clone would be like an identical twin – same genes, different person.*

Edmund Glasspoole: *Personally I quite like the idea of living 200 years on fresh organs taken from a mindless clone of myself. I don't see much harm in that.*

Henry Wotton: *It depends purely on the goals of whoever is doing the cloning. Organ farming for transplant, yes. Evil armies, no.*

PHOTO: CORBIS

WHAT THE PAPERS SAY

HENRY GEE

New research from leading science journals

The mystery of homosexuality has been cracked

MOST SPECIES OF animal display homosexual behaviour to some extent. It's been reported in everything from barn owls to bison. But theory tells us that traits that don't help an individual pass on its genes to the next generation, such as homosexuality, should soon disappear from a population. So how has it been favoured by evolution? Herein has always lain something of a mystery.

A new study may provide some clues. It shows that males inclined to display overt homosexual behaviour actually *increase* their chances of getting a girl who might otherwise be uninterested. The study concentrates on Atlantic mollies, small fish related to guppies. Female mollies prefer to mate with big, brightly coloured males, and ignore small, relatively drab males.

But as David Bierbach of the University of Frankfurt and colleagues show in new research published in the journal *Biology Letters*, female mollies will go for drabber males that have previously been involved in same-sex interactions, favouring them over drab males that have had no prior sexual interactions at all. In the world of Atlantic mollies, it seems the girls prefer males with a history of successful sexual conquest.

So it's easy to see how homosexuality can persist among fishes and other animals that swing both ways. Things get a bit more tricky when we try to explain how *exclusive* homosexuality is maintained. Humans, sheep and some birds display exclusively gay behaviour, in which members of one sex consistently pair only with individuals of their own sex. But again, a new study may explain this.

Andrea Camperio Ciani and Elena Pellizzari of the University of Padova in Italy, have spotted an interesting trend. They have found that the maternal grandmothers and aunts of homosexual men produce more offspring, overall, than the maternal grandmothers and aunts of heterosexual men.

In other words this research, published in the online journal *PLOS ONE*, appears to show that homosexuality is the result of having female relatives who are unusually fecund. This supports the idea of a model called sexual conflict. Males and females largely share the same genes, but genes that have one effect in one sex may have another effect in the other: genes that promote female fecundity might, for instance, result in homosexuality in male relatives. Provided that the overall number of offspring is maintained, the tendency for some males in the family to be gay will therefore remain.

It goes to show that our genes work in complex and subtle ways.

Henry Gee is a palaeontologist and evolutionary biologist, and a senior editor of the journal *Nature*

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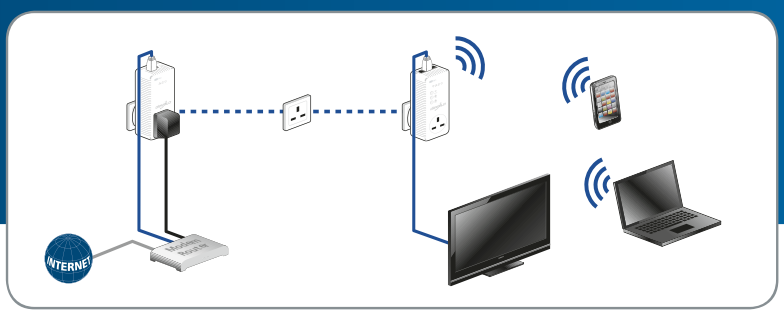

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Vitamin supplements may benefit those with nutritionally inadequate diets. † Professor Beckett is not cited in the capacity of a health professional, but as a product inventor and former Chairman of Vitabiotics.

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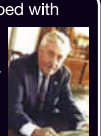

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INSIDE SCIENCE

ROBERT MATTHEWS

Explaining science to children can result in a bottomless pit of questions

WHAT'S THE ONE thing most people want to understand? Judging by requests typed into Google, it's not how to get rich, or why toast lands butter-side down. Touchingly, it's 'What is love?' When I typed that in, the top-ranked answers ranged from the coldly clinical – 'temporary insanity driven by hormones' – to touchy-feely blather – 'a force of nature'. But then, what else can one expect when asking questions about a vague, abstract noun? Love isn't exactly a hard-nosed scientific concept, is it?

Yet after 20 years of contributing to the Q&A section of this magazine, I've learned that even seemingly rock-solid scientific phenomena can turn to mush when you try to explain them. I first twigged this when I was given a magnet as a kid. Why did it pull things towards it – but not all things? The textbooks talked of magnets containing atoms whose own magnetic fields were all lined up. Not very illuminating. When I got to university, I was told it was about spinning electrons working together via some quantum effect called an exchange interaction. Still pretty hopeless. Finally, I heard the Nobel Prize-winning physicist and renowned teacher Richard Feynman being asked to explain magnetism (see p57 for more on him). It took him several minutes to get around to saying he couldn't. Well, that's not quite true. He actually said he *could* explain it – but not in terms of anything familiar to most people.

As so often, Feynman had highlighted a far bigger issue: what does it mean to 'explain' something? It's a question that hangs over every answer in the *Focus* Q&A section.

"I've learned that even seemingly rock-solid scientific phenomena can turn to mush when you try to explain them."

As Feynman suggests, it's often resolved by reference to more familiar things. Explanations about, say, the amazing abilities of animals often make reference to features familiar from the human body. Answers about, say, the expanding Universe frequently refer to a metaphorical inflating balloon with coins stuck on it. The challenge is to avoid triggering a cascade of yet more questions: yes, but how does a dog's amazing sense of smell actually work? What's the source of the cosmic 'gas' inflating the Universe?

Kids are notorious for repeatedly asking why in response to explanations that satisfy most adults. And that highlights a key feature of 'good' explanations. They're really just demonstrations that something odd actually isn't, and can be thought of in terms of something we already know – or at least have got used to. So if an explanation doesn't work, it's not necessarily the fault of the person doing the explaining. It can be that the person doing the asking just doesn't know enough stuff to relate it to.

That's why young kids have all those follow-up questions. It's also why it's hard for most people to understand Feynman's explanation of magnetism: it only makes sense if you're already familiar with quantum theory. But even Feynman admitted that quantum theory itself leads to a whole list of more 'why' questions, to which neither he nor anyone else has good answers. In the end, the ultimate answer to many questions is what irritated parents tell their kids: "That's just the way it is, okay?"

My personal dread, however, is being asked about issues so basic they can't be broken down and linked to other stuff at all. A classic example is 'What is time?' – the question American actor and science populariser Alan Alda recently challenged the scientific community to answer.

It will be interesting to see what responses leading scientists come up with. My bet is that none of them will really capture the full mystery of time. But they will at least show that, despite its image, hard science ultimately deals with issues every bit as ineffable as love. ■

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

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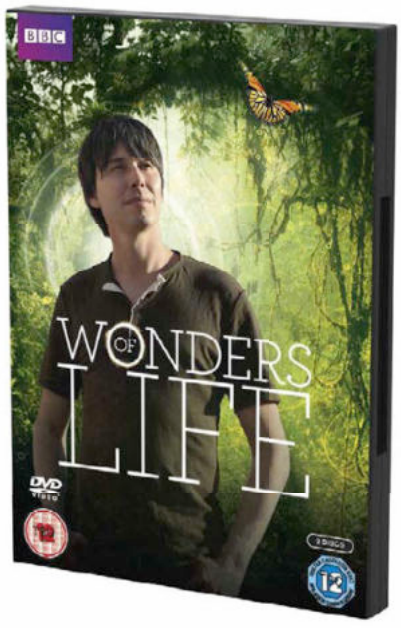

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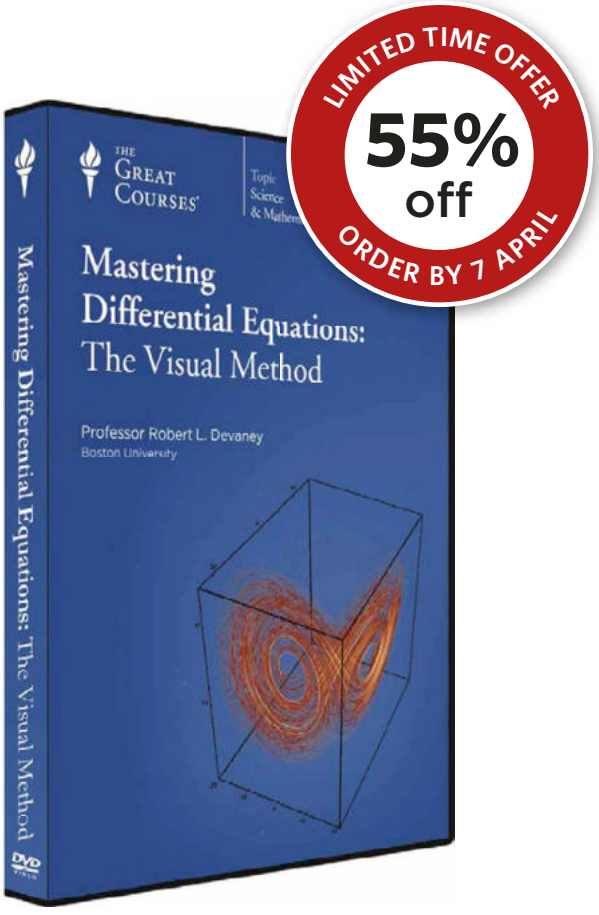

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HIDDEN TREASURES

HELEN CZERSKI

AS I WRITE this, I'm somewhere underneath a rain cloud that is covering most of the south of England. Just outside the window, millions of tiny packets of water are scooting downwards in response to the pull of the Earth. But if I could stop time, get out my magnifying glass and peer in at an individual droplet, what would I see? What shape is a raindrop?

First things first: it's not the classic teardrop shape that we see splattered across weather maps. Raindrops come in many shapes and sizes, but a teardrop isn't one of them. A falling raindrop is like a mini battleground, with ongoing skirmishes between the different forces pushing and pulling on it. The most dominant force is surface tension, that weird tendency of water to behave as though it has an elastic skin. Water molecules tend to move towards places where they are surrounded by other water molecules, and this is why water doesn't have pointy bits. It takes energy to pull a water molecule away from all the others, as if it was attached by a piece of elastic. So any molecules sticking out quickly get pulled back, and water surfaces are generally smooth.

Left to itself, surface tension would make all raindrops spherical. But rain falls through our atmosphere, a jumble of gas molecules zooming about and continually bumping into each other. The raindrop pushes the gas molecules out of the way as it falls, but in the best tradition of Newton's third law, the gas molecules push back. That upward force (drag) on the drop pushes the bottom of it towards being flatter, leading to a shape like a falling jellyfish without the tentacles. But surface tension is pulling the droplet towards being spherical. The winning balance depends on the drop size – smaller drops are close to spherical and they get more and more pancake-shaped as they grow.

It's not a peaceful competition though. The drops wobble as they respond to slight changes in the airflow, and a truce is never reached. The droplet is constantly being pushed out of shape and pulled back, and it has a shifting, oscillating surface of beautiful eccentricity. If you could zoom in on this with a magnifying glass, you'd see a weird, sparkly, curvy gem that will only have this exact shape for just one instant.

"A falling raindrop is like a mini battleground, with ongoing skirmishes between the different forces pushing and pulling on it"

As they fall, raindrops grow. They get extra water from the saturated air, or they bump into other droplets and snaffle them up. It's just as well that this process can't continue indefinitely – can you imagine what a rainy day would be like if raindrops were football-sized? Painful! It would be like vertical cannon fire from the clouds.

A battle between forces means that a raindrop's shape is constantly changing

So how do we avoid being smashed to pieces every time there's a big thunderstorm? As droplets get bigger, surface tension starts to lose the battle to hold the drop together. Big droplets spread out to become wobbly pancake shapes, and eventually the push from the air breaks these big drops apart. The break-up can be violent, resulting in a mini-explosion of new droplets. These new droplets continue downwards, each one a new battleground between air drag and surface tension. So raindrops never get bigger than a few millimetres in diameter. Greenhouses and your head are safe.

So next time you're staring at the rain, feeling grumpy that you're stuck inside, think about what's out there. These are millions of falling, shape-shifting jewels, each one the beautiful result of a tug of war. It's such a shame that the idea of a 'tear-shaped' raindrop exists – reality is a million times better. ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose shows include *Operation Iceberg* and *Orbit*

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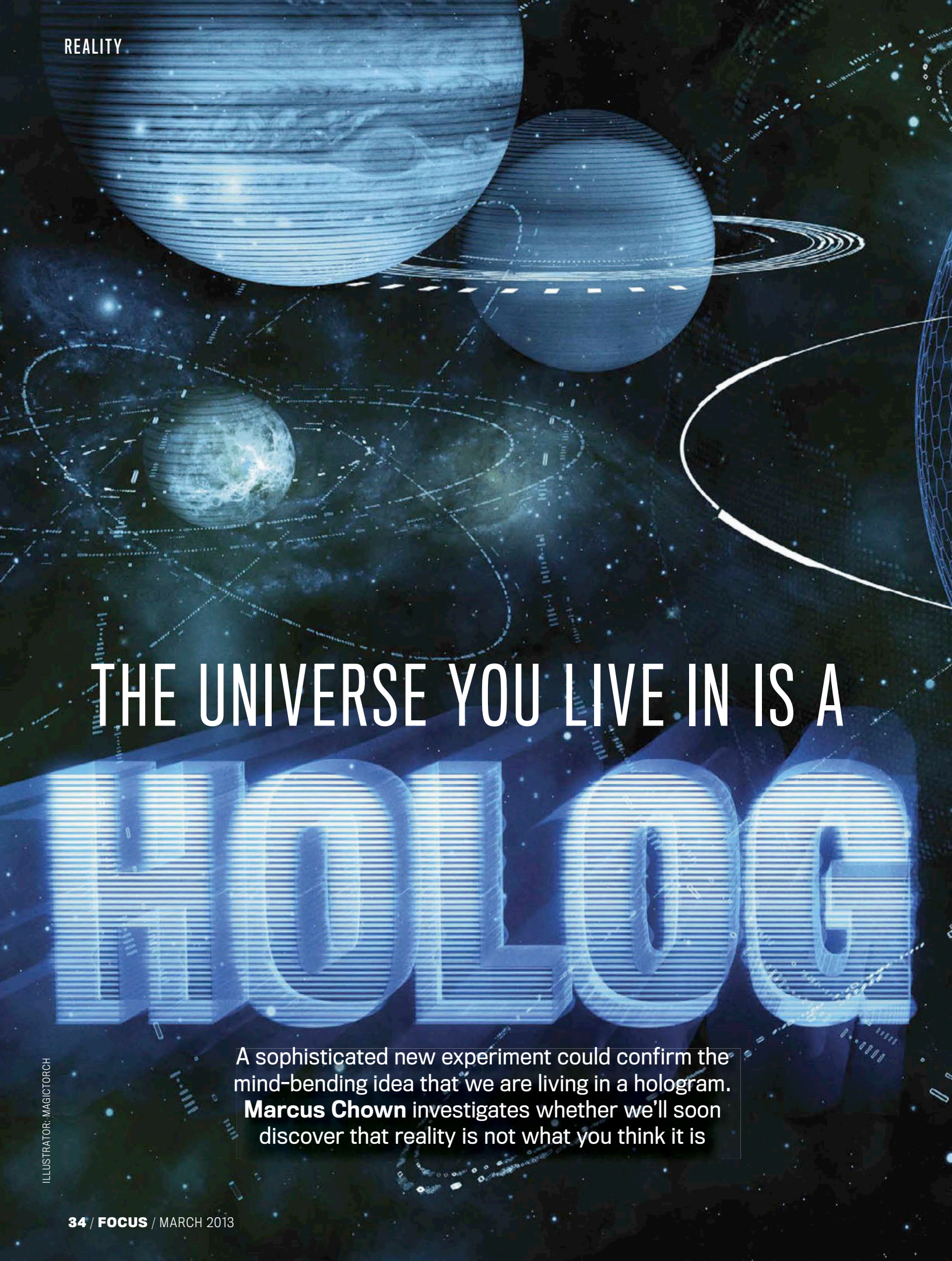


THE UNIVERSE YOU LIVE IN IS A HOLOG

A sophisticated new experiment could confirm the mind-bending idea that we are living in a hologram. **Marcus Chown** investigates whether we'll soon discover that reality is not what you think it is

ILLUSTRATOR: MAGICTORCH


RAM

FERMILAB, THE AMERICAN particle accelerator facility near Chicago, has just seen the completion of a peculiar scientific instrument. Its purpose is to probe space-time and demonstrate that, far from being smooth, as Einstein believed, it is grainy like a newspaper photograph viewed close-up. If the Fermilab 'Holometer' succeeds, incredibly, it may reveal that the Universe is actually a hologram – a 3D representation of an underlying 2D reality. It would mean that we – and the planet on which we live – are holograms.

Over the coming months the Holometer will be switched on, beams of laser light racing along tubes to measure space-time at the smallest of scales. It will show whether space and time stand still, or whether they shift around a tiny bit. If there's movement or some 'blurring', it would show that the Universe is a hologram – just like the blurred security image on a credit card.

The suggestion that we are living in a giant hologram is surely one of the most bizarre ideas to come out of modern physics – proof, if proof were needed, that science is indeed far stranger than science fiction. Even stranger, the idea has its origin not in cosmology – the study of the large-scale Universe – but in the esoteric field of black holes.

Black holes are born when a massive star reaches the end of its life and shrinks catastrophically, crushing it to a point-like 'singularity'. Not even light can escape the gravitational clutches of a black hole, hence its name. The vanishing of a star in such a dramatic way was not a problem for physics until, in the 1970s, Stephen Hawking showed that, paradoxically, black holes are not completely back. They radiate into space so-called Hawking radiation until there is nothing left of them and they disappear.

The trouble is that Hawking's discovery implies that, when a black hole 'evaporates', all information about the star that shrunk to create the black hole – the type and location of all its atoms, for instance – would seem to disappear too. This contradicts a fundamental edict of physics that 'information' can never be created or destroyed.

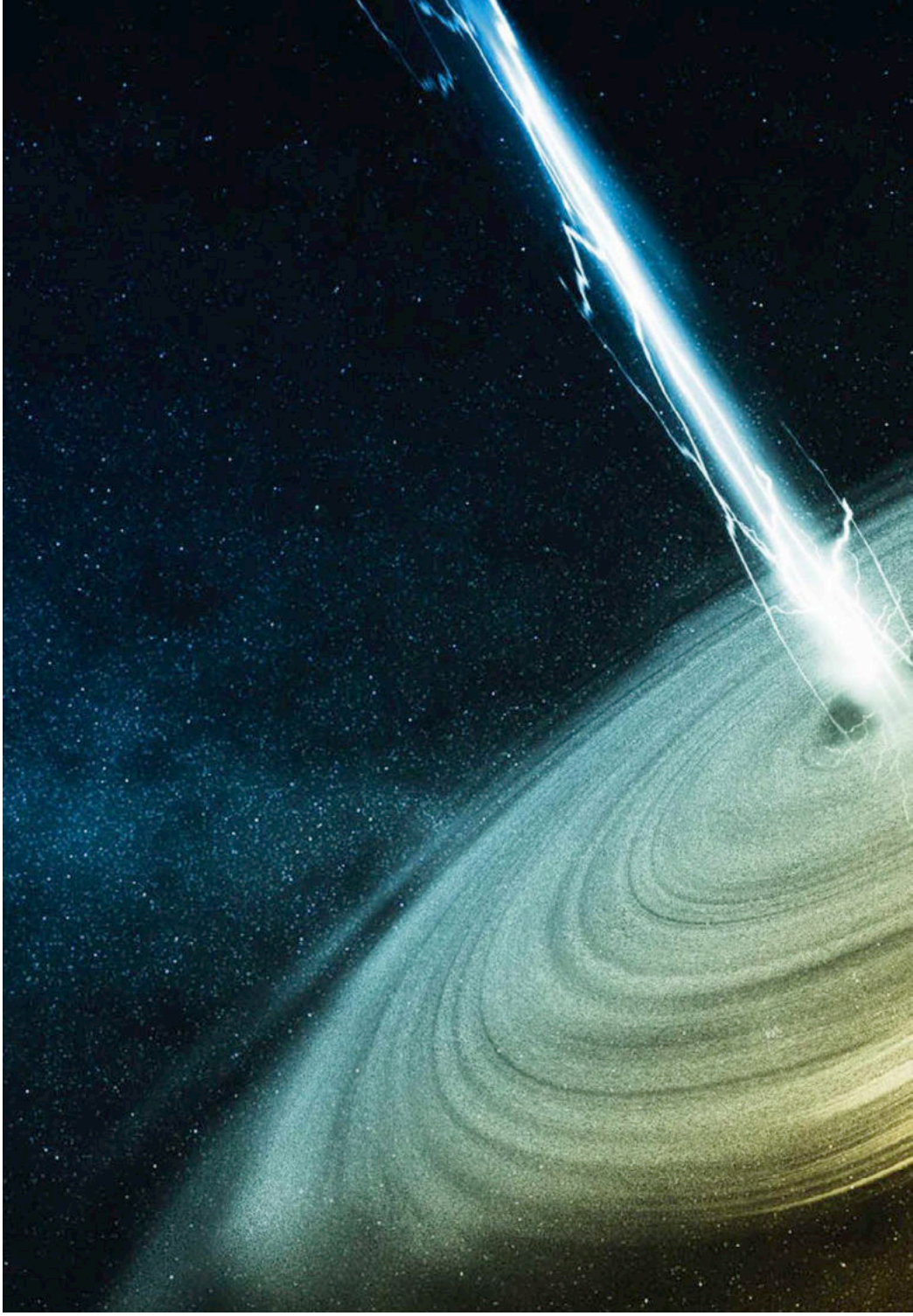


PHOTO: THINKSTOCK, ALAMY

MISSING INFORMATION

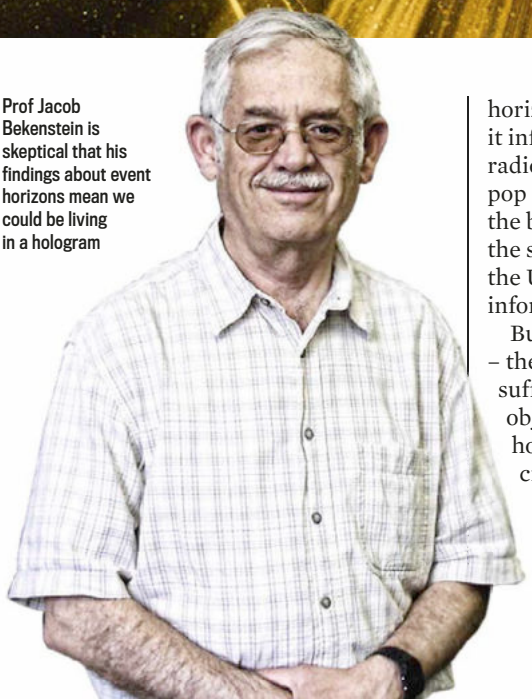
A clue to the resolution of the black hole information paradox, as it became known, came from Israeli physicist Professor Jacob Bekenstein. He discovered something profound about the 'horizon' – the imaginary membrane that surrounds a black hole and marks the point of no return for in-falling matter. Bekenstein found that the surface area of the horizon is related to the 'entropy' of the black hole. In physics, a body's entropy is synonymous with its microscopic disorder. Crucially, entropy is intimately related to information.

This is the key clue to resolving the black hole information paradox. In 1997, string theorist Professor Juan Maldacena of Princeton's Institute for Advanced Study in the US showed that it is in the horizon that the information that describes the star may be stored – as microscopic lumps and bumps. So, when the black hole sends out Hawking radiation from the vicinity of its

"The Holometer's cost is small for an experiment testing such a fundamental question"

Professor John Cramer of the University of Washington

Not even light can escape the clutches of a black hole, but information about what gets sucked in is emitted as Hawking radiation



Prof Jacob Bekenstein is skeptical that his findings about event horizons mean we could be living in a hologram

horizon, the radiation has impressed on it information about the star, just as the radio waves from BBC Radio One have pop music impressed on them. So, when the black hole disappears, the 'song' of the star is not lost at all. It is broadcast to the Universe as Hawking radiation. No information is ever lost.

But all this implies that a 2D surface – the horizon of a black hole – can store sufficient information to describe a 3D object – a star. This is exactly what a hologram, such as the one on your credit card, does.

This might all seem an esoteric result about an esoteric type of celestial body – a black hole. But,

A black hole's event horizon stores information about a 3D object on a 2D surface, just like your credit card's hologram

in the late 1990s, Professor Leonard Susskind of Stanford University in California made a surprising connection. The Universe, like a black hole, is surrounded by a horizon. It is a horizon in time rather than in space but it is a horizon nonetheless. So, reasoned Susskind, the information describing the 3D Universe might be stored in its horizon.

What this means is open to a wide range of interpretations. A conservative interpretation is simply that the Universe contains a lot less information than we imagined. A more extreme interpretation is that the Universe is truly a hologram – a 2D object stored on the cosmic horizon which creates the illusion of a 3D universe. In some sense, 'you' would be a 3D projection of a flat you. Bekenstein, however, is sceptical of Susskind's extension of his black hole idea to the Universe. "My result is not applicable to horizons which are not event horizons," he says. However, there is other evidence that the Universe contains less information than its three space dimensions would imply, and this is now generally accepted by physicists.

GRAINS OF TRUTH

If Susskind and others are right about the Universe being holographic, one thing would appear to follow. A hologram is more blurry than the object it depicts – just like the image on a credit card. And this has implications for space-time.

It turns out that space is like the ocean. Observed from a great height – from the perspective of a bird for instance – it looks smooth. Observed close-up, from the perspective of a boat, it is rough and choppy. In fact, space-time is believed to become so choppy that it loses its

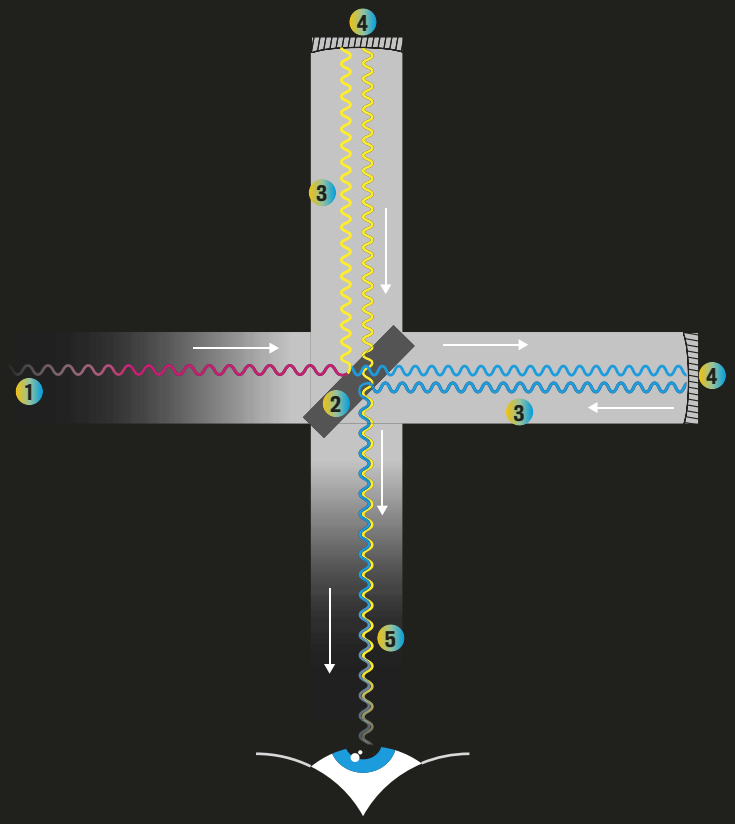
THE REALITY MACHINE

How the Holometer will detect whether everything in the Universe – including us – is actually a hologram

HOW WILL IT WORK?

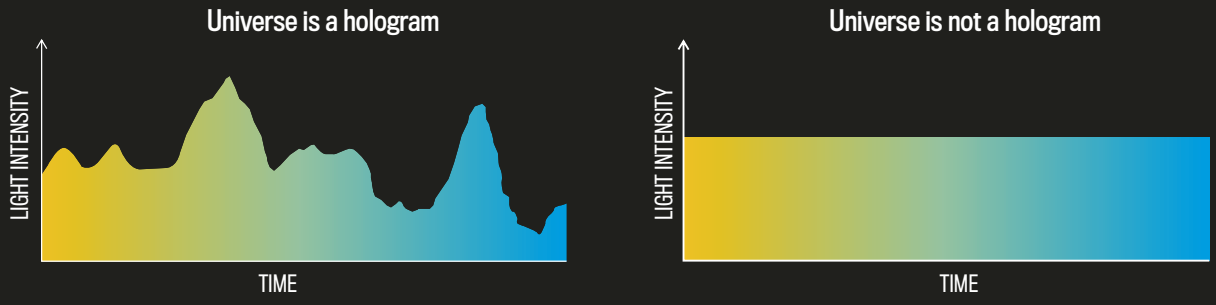
A beam of light is split and then recombined to spot any minute imperfections in space-time

1. Light comes from a 2W laser that spits out infrared light.
2. A half-silvered mirror, the 'beam splitter', creates two beams by reflecting half the incoming light and allowing the other half to pass through.
3. Two tubes that are 40m long and with all the air pumped out allow the light to travel unhindered.
4. If the suspended mirrors are jostled by the graininess of space-time, it will leave its mark on the light.
5. The two light beams are combined. If the intensity of the combined light fluctuates, it reveals the jitter of the mirrors – a strong indication that the Universe is holographic.



WHAT WILL IT SEE?

The combined beam in the Holometer will reveal the true nature of space-time



If the Universe is a hologram, the jitter of space-time will cause the length of the Holometer's arms to vary. The beams will go in and out of phase and the intensity of the re-combined beam will fluctuate.

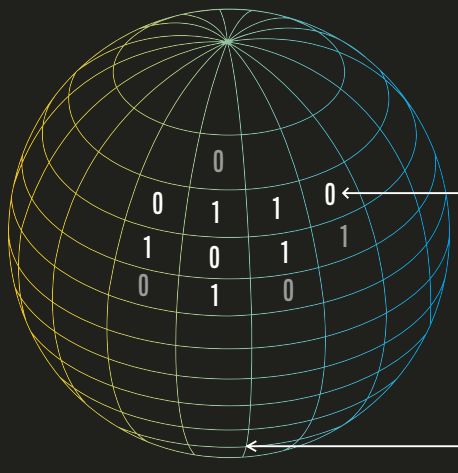
If the Universe is not a hologram, the two light waves will remain in sync, combining to create a constant light intensity.

HOW 2D BECOMES 3D

The fact that we experience three dimensions could simply be an illusion

Prof Hogan bases his argument about reality on a particular theoretical model of 2D space at the submicroscopic scale from which familiar 3D space 'emerges' on the large scale. He believes it is similar to Susskind's holographic idea, but this is disputed.

If Hogan finds graininess, he believes he will have shown that the Universe is truly holographic – that is, the information necessary to describe it could be written on a 2D surface. It's only on the large scale that a third dimension emerges. This is why we have no sense that we, and everything around us, are 2D.



Every bit of information about the Universe is stored in two dimensions

Somehow, a three dimensional Universe emerges from this limited information

PHOTO: REIDAR HAHN/FERMILAB X2 ILLUSTRATION: RICHARD PALMER

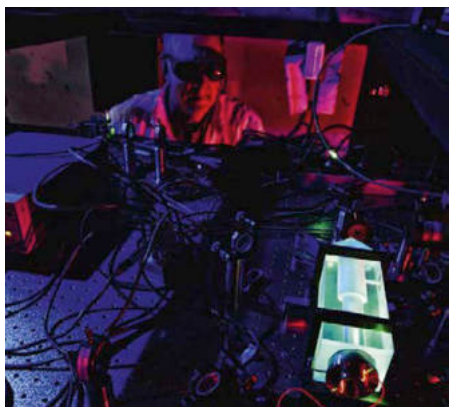
The Holometer has two 40m tubes that carry lasers through a vacuum to mirrors. The vacuum enables light to travel unhindered

smoothness entirely at the size of the 'Planck scale', which is about 10^{-35} metres, or about 10 trillion trillion times smaller than a typical atom. But, if the Universe is a hologram, it should be much grainier. It would mean we wouldn't have to zoom into a scale of 10^{-35} metres to see things get choppy – making the graininess easier to detect.

For a time in 2008, it did indeed seem as if the graininess of space-time had been detected, proving the idea of the holographic Universe. An Anglo-German experiment called GEO600 near Hanover in Germany was looking for gravitational waves. These are ripples in the fabric of space-time, predicted by Einstein's theory of gravity, General Relativity, and thought to be radiated by violent events such as the explosion of stars and the birth of black holes. As gravitational waves pass by, they alternately squeeze a stretch space in perpendicular directions. The GEO600 interferometer was looking for this distortion with two perpendicular 600m 'rulers' made from laser light. The light travels back and forth along the arms of the interferometer, bounced repeatedly

"This is a journey into the unknown. There are no well-tested ideas to tell us what we will find"

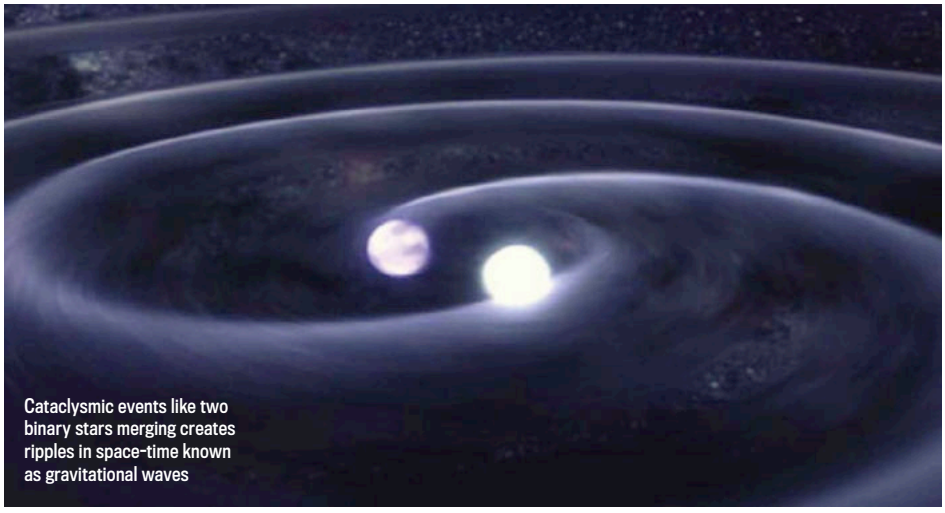
Professor Craig Hogan, University of Chicago and Fermilab



The Holometer is a highly sensitive instrument and needs to be calibrated to iron out any external sources of vibration

from suspended mirrors. And it was these mirrors that revealed something odd. They seemed to be jittering, like a branch being buffeted by the wind. And nobody could figure out why.

Enter Professor Craig Hogan of the University of Chicago and the nearby Fermi National Accelerator Laboratory (Fermilab). When he heard about the unexplained jitter, or 'noise', he



Cataclysmic events like two binary stars merging creates ripples in space-time known as gravitational waves

immediately thought GEO600 had accidentally found the graininess of space-time. The mirrors were being jostled, he reasoned, by its choppiness. The Universe was indeed a hologram.

Unfortunately, the GEO600 experimenters later found the source of the noise and it turned out to be mundane. It was simply an artefact of the way the experimenters recorded the light from their instrument. When they changed their readout method, the noise went away.

But Hogan was undeterred. The idea grew in his mind of building an instrument hugely more sensitive than GEO600 and specifically dedicated to finding the trembling of space-time at the Planck scale itself. Thus the Fermilab Holometer was born.

Hogan did not even assume the reasoning of Susskind – that the Universe's horizon contains all its information. He simply assumed that, at the sub-microscopic, choppy level, space-time is fundamentally 2D. On the larger scale, a third dimension emerges. Emergent phenomena are seen everywhere in nature. The atoms that make up a wall painted blue are in no sense blue. But when there are large numbers of atoms clumped together, the property of blue emerges.

TESTING REALITY

The Holometer consist of two perpendicular arms, each 40m long. Laser light enters the instrument, is split by a 'beam-splitter', travels down each arm, before bouncing off a suspended mirror and travelling back the way it came. The two beams then recombine (see 'The reality machine', on p38).

If the two arms keep a constant length, the two light waves will combine and

FOR and AGAINST: Will the Holometer prove we live in a holographic Universe?

NO

Professor Raphael Bousso
University of California at Berkeley

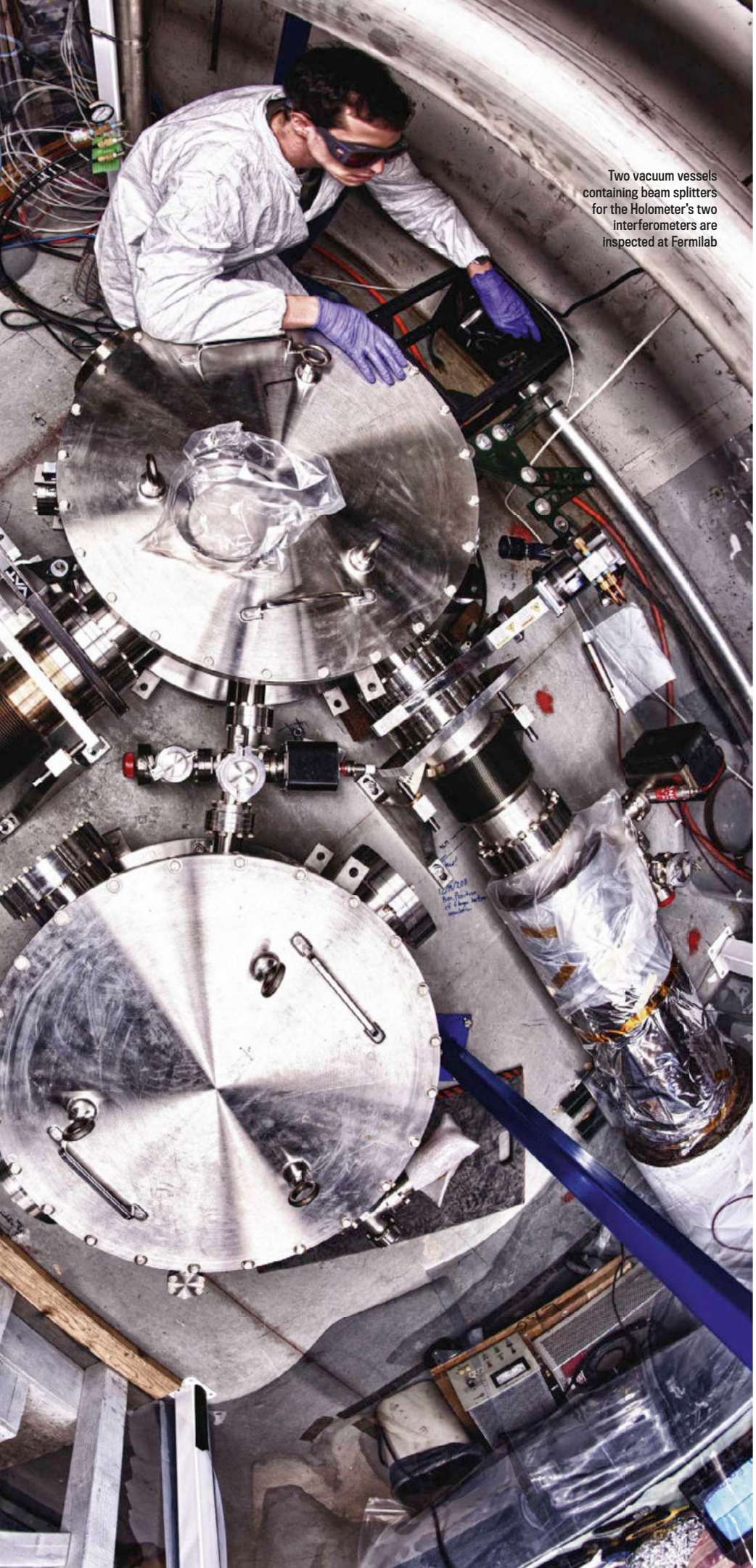
"The holographic principle does not imply that there will be quantum jitters in Hogan's experiment. So it will see nothing. The Holometer has garnered an inordinate amount of attention in the blogosphere, raising unrealistic expectations. When there's no signal, there is going to be a backlash saying that the Holographic principle isn't valid, and we'll look like we're on the defensive."

YES

Professor Craig Hogan
University of Chicago and Fermilab

"Our prediction of quantum jitter does not come from the 'holographic Universe' idea. Instead, it's based on a particular model of how 3D space-time 'emerges' from 2D space-time at the submicroscopic level. Nevertheless, it's a similar idea. Bousso's right that a negative result will not disprove holography. And indeed, perhaps he is worried that we will find nothing and that this will unfairly discredit the holographic Universe. I give the scientific community more credit than that."

PHOTO: NASA, REIDAR HAHN/FERMILAB



Two vacuum vessels containing beam splitters for the Holometer's two interferometers are inspected at Fermilab

create a constant intensity with time. But, if space-time is choppy the arms will fluctuate in length from moment to moment. This will cause the light waves to go in and out of phase, one instant reinforcing, the next partially cancelling, causing the intensity of the combined light to fluctuate.

The Holometer, built using a tunnel that was part of an old Fermilab experiment, will actually consist of two interferometers, one on top of the other. If they both show exactly the same fluctuation with time, the experiment will know it is not an artefact – a mundane vibration in the Fermilab building, or fluctuations from discrete laser photons. It would be something caused by fundamentally new space-time physics.

GREAT EXPECTATIONS

"I'm glad the Holometer has been constructed at Fermilab and is running," says Professor John Cramer of the University of Washington in Seattle. "Its cost is very small for an experiment testing such a fundamental question." At roughly $1 million (£623,000), the cost of the Holometer is a drop in the ocean compared with the £4.4 billion price tag of CERN's Large Hadron Collider.

"The Holometer should be operating and collecting data in a few months," says Hogan. But it will take a while to reach its optimum performance. "Sources of environmental interference will have to be tracked down." For instance, the experimenters will have to understand spurious causes of vibration such as the tremors caused by cars going by on the street – so they can subtract them. "We hope it will be working at its optimum level in about two years' time," says Hogan.

Cramer has high hopes. "Experimentalists are optimists by natural selection, because otherwise they would never be foolish enough to do experiments," he says. Hogan is trying to keep a lid on his enthusiasm. "I try not to get carried away thinking about the results," he says. "This is a journey into the unknown. There are no well-tested ideas to tell us what we will find." ■

Marcus Chown is a former radio astronomer at the California Institute of Technology and the author of *We Need To Talk About Kelvin*

Find out more

The Holographic Universe
By Michael Talbot (HarperCollins, 1996).

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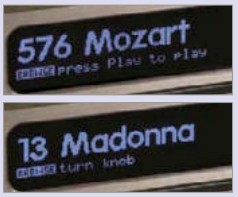

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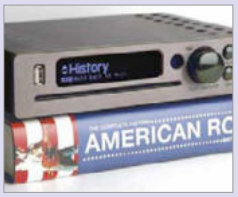

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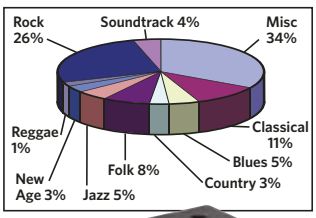

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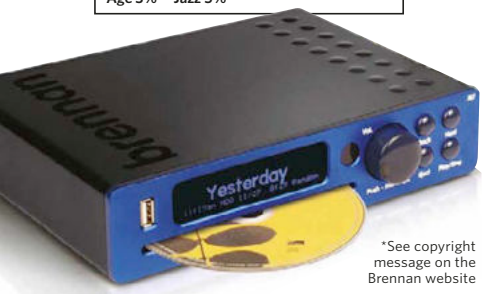

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ARE WE LIVING IN A SIMULATION?

It's an age-old question, but one that physicists might soon be able to answer. **James Lloyd** talks to Silas Beane, who thinks he's found a way to test whether reality really is real...

The idea that we're all pawns in a simulated universe isn't a new one by any means. In his famous *Allegory Of The Cave*, the Greek philosopher Plato illustrated how what we assume to be real can so easily turn out to be an illusion. Some 2,000 years later, the French philosopher Descartes speculated about the existence of an evil demon who is constantly deceiving us with a fabricated reality.

But if we really are living in a simulation, how could we ever find out? In cult sci-fi film *The Matrix*, the main character Neo is presented with two pills. His dilemma: take the blue pill and remain in the artificial reality forever, or take the red pill and escape into the real world.

Sadly for us, it's not quite that easy. But a team of physicists, including Silas Beane at the University of Bonn in Germany, have announced that they have found a way to prove once and for all whether we're all actually living inside a simulation.

PHOTO: GETTY

INTERVIEW SILAS BEANE

Silas Beane is a theoretical physicist at the University of Bonn

Who first suggested that we might be living in a simulation?
There have been variants of this idea going all the way back to Plato, but my collaborators and I are interested in the work of a Swedish philosopher at the University of Oxford called Nick Bostrom. He came up with an interesting argument: if computers keep growing in power as they're growing now, then our descendants will be able to simulate reality.

And if our descendants don't have any qualms about simulating reality, then they're probably going to perform a lot of simulations. So we should ask ourselves the question: what are the odds that we're in the one true reality, and not one of these many, many, many simulations?

How does this relate to your own work?
About eight years ago my colleagues and I started to use high-performance computers to simulate a fundamental force of nature called the strong nuclear force. We decided we may as well call ourselves 'universe simulators' because that is indeed what we're doing – we're simulating the strong nuclear force within these little boxes, which enables us to calculate the properties of matter.

What is the strong nuclear force exactly?
It's one of the four fundamental forces, along with the weak nuclear force, gravity and electromagnetism. We know the equations for this force – they describe the interactions between fundamental particles called quarks and gluons. The problem is that although we know the equations, their solutions are very complicated. That's why we need the world's most powerful supercomputers to carry out our simulations.

So by computing this force, are you able to simulate the Universe?
Not quite. The box sizes that we're currently simulating are roughly the size of a proton – more or less 1 femtometre [one millionth of a nanometre] across. So it's still a very, very small number. But if you extrapolate into the future, then if technology keeps progressing, there'll come a point when the box sizes are large enough to contain microscopic objects such as cells, and then even macroscopic objects such as you and I. Eventually, with enough computing power, it'd be possible to simulate an entire Universe.

How could we find out if we're living in a simulation?
British physicist John Barrow pointed out that if we're being simulated, then we might expect to see glitches on the part of the simulators. This was something that resonated with us because when we do our calculations, we're always worried about glitches and work hard to remove them.

How could we spot these glitches?
We only know one way of simulating the strong nuclear force, and that's to use a grid – a kind of framework that divides up space-time into a lattice structure. We use that as a fundamental assumption, that whoever's simulating the Universe is also using a grid. And if we're being simulated in a box with a finite grid size, then by the rules of quantum mechanics there's a maximum energy that particles can have. As particles get closer and closer to this maximum, they probe smaller and smaller regions of space. So for large enough energies, you'd see the lattice structure. That's the glitch we're looking for.

So we could see the grid by looking at high-energy processes?
Yes – one place where you would see these effects is in the very high energy range of the cosmic ray spectrum. In our work, we consider collisions between extremely high-energy cosmic rays and extremely low-energy photons left over after the Big Bang. Our calculations show that, in the presence of a grid, the stuff coming out of these collisions should direct itself along certain axes, not equally in all directions. So if you could detect these directions with sufficient accuracy, you could determine if our Universe is indeed built on a grid.

Could we measure this in the 'real' world?
In principle, yes. We'd have to detect these cosmic ray collisions along different angles in the sky to try to figure out if there's some preferred direction. These events are extremely rare, so it's not clear to us exactly how we'd go about doing that. We're *theoretical* physicists, after all!

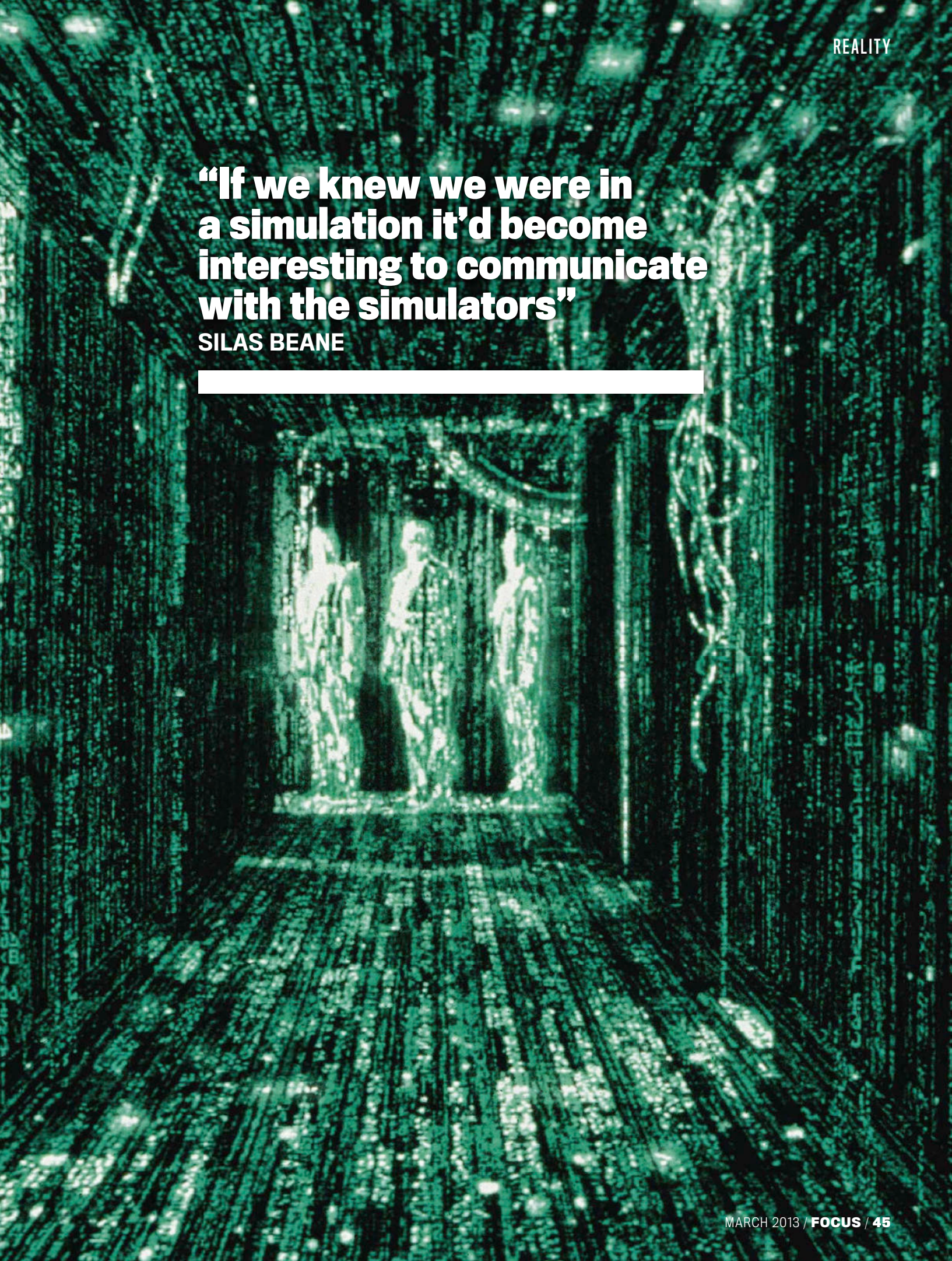
If the Universe is an illusion, what could we do about it?
I think if we knew we were in a simulation, then it'd become interesting to communicate with the simulators. There are also arguments to suggest we wouldn't be the only simulation, so it might be possible to communicate with others.

Why might an advanced civilisation decide to simulate a Universe?
For me, it seems likely that our simulators would be interested in simulating many universes, varying different parameters to see how things turn out. For instance, if they changed the fundamental constants of nature or the masses of particles, maybe silicon-based life would emerge instead of carbon-based life like us. I think they'd be interested in observing the evolution and ultimate fate of these universes.

So our creators would be doing what you're doing now but on a much bigger scale?
[Laughs] Exactly... it's nice to have the scientists in charge for a change.

Do you think we're living in a simulation?
I find Bostrom's argument compelling – and quite depressing, too. To me, the crux of his argument is that the only way we can conclude that we're not in a simulation is if we're going to destroy ourselves in the near future. Or alternatively, maybe when the technology arrives, humans will decide not to simulate universes after all? Maybe, but humans will do whatever we're capable of doing... right? ■

PHOTO: WARNER BROTHERS/KOBAL



“If we knew we were in a simulation it’d become interesting to communicate with the simulators”
SILAS BEANE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POMPEII: UNCOVERED

On the eve of a landmark British Museum exhibition, we explore the past, present and future of Pompeii, and why Mount Vesuvius is deadlier than ever

WHEN VESUVIUS ERUPTED in 79AD it buried the Roman city of Pompeii and the town Herculaneum, along with many of its residents, under ash and pumice. As the British Museum prepares to exhibit hundreds of artefacts from the sites, we asked leading experts in archaeology and volcanology to tell the story – past, present, and future – of these settlements and their volatile neighbour.

PHOTO: GETTY

Bill McGuire
is a geohazards expert at the Aon Benfield UCL Hazard Research Centre

Mike Pitts
is a writer and the editor of *British Archaeology* magazine

THEN (79AD)

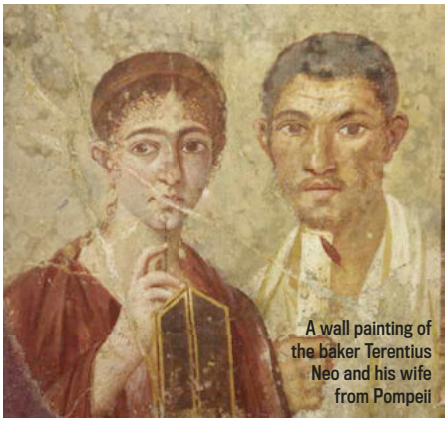
POMPEII

POMPEII IS ONE of the must-see sights of Italy alongside Herculaneum, a town that also perished when Mount Vesuvius erupted in 79AD. The city is important to us because of the way Vesuvius both destroyed and preserved it, but in the 1st Century AD it had little special significance. If there were any tourists, they were more likely to be strolling the beach at Herculaneum – and perhaps hoping for a glimpse of Emperor Caligula at his luxury villa – than in the markets or industrial wharves of Pompeii.

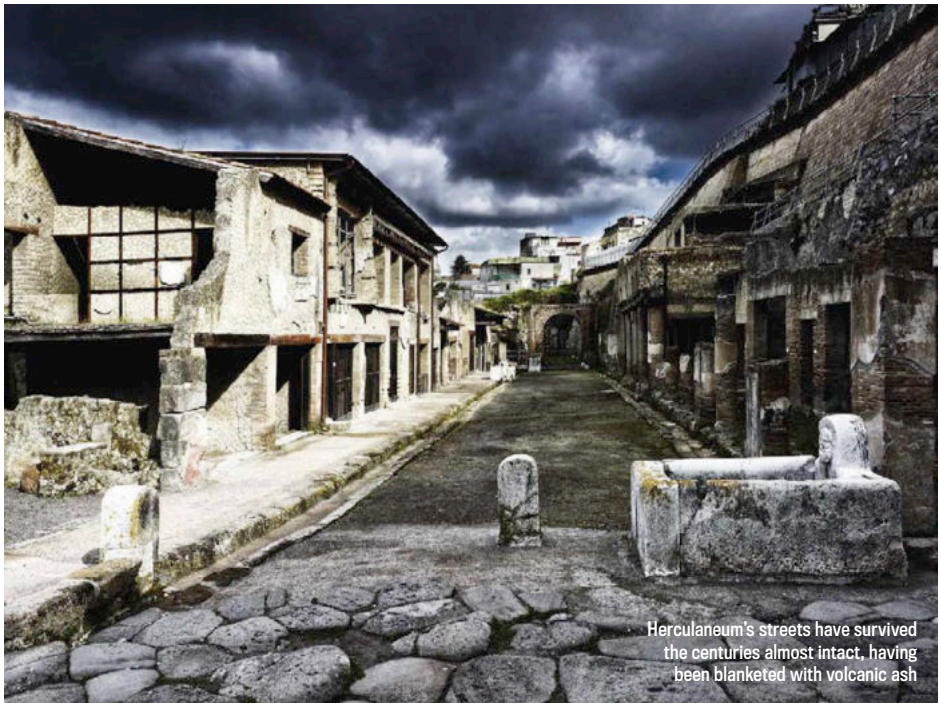
Locally, however, Pompeii was an important inland port, a place of trade, industry and business, famed for its fermented fish sauce. Its people were a mix of wealthy elite, professionals and slaves. Inscriptions attest to bakers and bath-attendants, grape-pickers and prostitutes. The recent decipherment of writing tablets from Herculaneum suggests that over half its population were slaves or freed slaves. It reveals the true extent of this infamous aspect of Roman society.

There is no reason to think Pompeiians were anything other than typical Roman citizens, so their remains can probably speak for many across Italy at the time. While they suffered the diseases and discomforts that still affect us today, in general their health beyond childhood (higher infant mortality is likely) was not greatly different from our own. However, one study suggested an important exception to this rule: the state of teeth and jaws point to poor dental hygiene.

The slopes of Vesuvius were known for its fertile soils and wine from Pompeii was an important export – at least one wine jar made it all the way to England. But people were less aware of the volcano's dark side. The city had been badly damaged by severe earthquakes 15 years before the eruption. Yet none of this was connected to volcanism. There was nothing to fear...



A wall painting of the baker Terentius Neo and his wife from Pompeii



Herculaneum's streets have survived the centuries almost intact, having been blanketed with volcanic ash

PHOTO: THE BRITISH MUSEUM X2, THE ART ARCHIVE

VESUVIUS

MOUNT VESUVIUS IS a young and somewhat unpredictable volcano that started growing just 25,000 years ago. The volcano alternates phases of almost continuous activity with episodes of total quiescence. It seems very likely that the 79AD blast brought to an end such a quiet period, so that the citizens of Pompeii and neighbouring communities would have had no experience of previous eruptions and therefore no awareness of the dreadful threat that Vesuvius presented. Most would not even have known that their local mountain was a volcano.

No eruption occurs without warning signs, as rising magma needs to break rock and make space for itself if it is to reach the surface. This reveals itself through small earthquakes and a swelling of the ground surface, both of which we could routinely detect today. Prior to the 79AD explosion, however, any ground swelling would have been too small to be noticed, while the common occurrence of small tremors in this tectonically lively region would have ensured that they were largely disregarded by the local population.

When Vesuvius finally blew its top, however, it did so with a violence and speed that no-one could fail to notice. Detailed analysis, over the past decade, of the deposits left behind by the eruption, allows the sequence of events to be unravelled. An opening blast, far more powerful than the Hiroshima atomic bomb, hurled a column of ash and debris to a height of 15-30km. At least five colossal vertical blasts followed, interspersed with ground-hugging pyroclastic surges that hurtled down the volcano. More than 2,000 inhabitants who had not already fled were rapidly engulfed in these lethal flows of incandescent ash and boiling gas. Death was agonising but quick; a single breath burning the throat and destroying the lungs.

Forty-eight hours later, the eruption had ceased, but its legacy lingered on in a dramatically changed landscape. The town of Pompeii had vanished, buried beneath a blanket of ash and pumice up to 6m deep. Even the coastline was different; ash and mud pouring into the Bay of Naples from the Sarno River pushing it a further kilometre seaward.

A cast of a Pompeii citizen that was petrified in volcanic ash; death would have been agonising but quick as the lungs were incinerated with a single breath

NOW

POMPEII

SINCE ITS DISCOVERY in 1748, people have been digging up Pompeii for over 250 years. You might think there was little more to learn, but as Paul Roberts, curator of the British Museum exhibition says, if there's one thing that recent research at Pompeii and Herculaneum has made clear, it is that "It's not so clear". We are far from really understanding what made Pompeii tick.

Modern science and archaeology have replaced the old-style treasure-hunting for fine artefacts and wall paintings. In the process, everyone has realised how much knowledge was lost through earlier work – and how much more we can learn now. The excavation of houses still sealed under ash has stopped. Yet researchers from up to 20 nations are engaged at Pompeii, recording and analysing their predecessors' excavations, bringing new science to old finds and making new discoveries as they try to save and restore what remains.

Take gardens. Early students had questioned whether the lush gardens pictured in wall paintings could have been real. But detailed examination of those parts of Pompeii that were not built over revealed how much of the town had been green, from kitchen plots to orchards and vineyards, as well as impressive formal gardens with pools and fountains. Recent work has proved the use of a huge variety of trees, flowers, herbs and vegetables through the study of wood, pollen, seeds and other plant remains.

"In one house 13 healthy people died: their ages suggest grandparents, parents and their children."

It has been estimated that at least a fifth of the entire town was green space.

It is microscopic finds like this that are now helping to show what was happening in Pompeii, from fish-salting to horse-stabling. A recent excavation found the remains of a tethered mule, lying slumped against its feeding trough surrounded by bedding and fodder. Subsequent analysis of this revealed grasses, wayside plants, cereals, olives and walnuts. Recovering such detail is slow work. A University of Cincinnati project uses iPads in the trenches to keep up with the huge amount of data its excavations produce.

The body casts at Pompeii are justly famous, but it is the skeletons themselves that are now proving to be the more informative. Studies that include medical scanning of casts, and searches of centuries of museum collections have shown it was not just the weak and infirm who failed to escape Vesuvius's wrath. In just one house, 13 healthy people died: their ages suggest grandparents, parents and their children, one of whom was a pregnant teenager.

NOW

VESUVIUS

VESUVIUS RIGHTLY holds a place at the top of a tally of the world's deadliest volcanoes because of the sheer number of people now living in very close proximity. Following the deadly eruption of 1631, Vesuvius was active almost continuously, right up until the wartime eruption of 1944. Since then, however, the volcano has been quiet.

While Vesuvius has shown little sign of activity for close to 70 years, the same cannot be said of the inhabitants of the region. Rapid post-war construction, much of it unregulated or illegal, has resulted in a huge increase in the numbers of people living on its flanks. The population of the highest-risk 'zona rossa' (red zone) has exploded to more than 600,000, all of whom will be in grave danger when the volcano once again springs to life. In a belated attempt to tackle this problem, the civil authorities are now offering financial incentives to try and encourage people to move to safer locations, but this has had little effect and is unlikely to make much of a dent in the numbers at risk.

Meanwhile, the volcano has shown little sign of a return to active life. While this is broadly regarded as a good thing, there is also some concern that the longer the volcano slumbers, the more violent the blast will be that heralds its awakening.

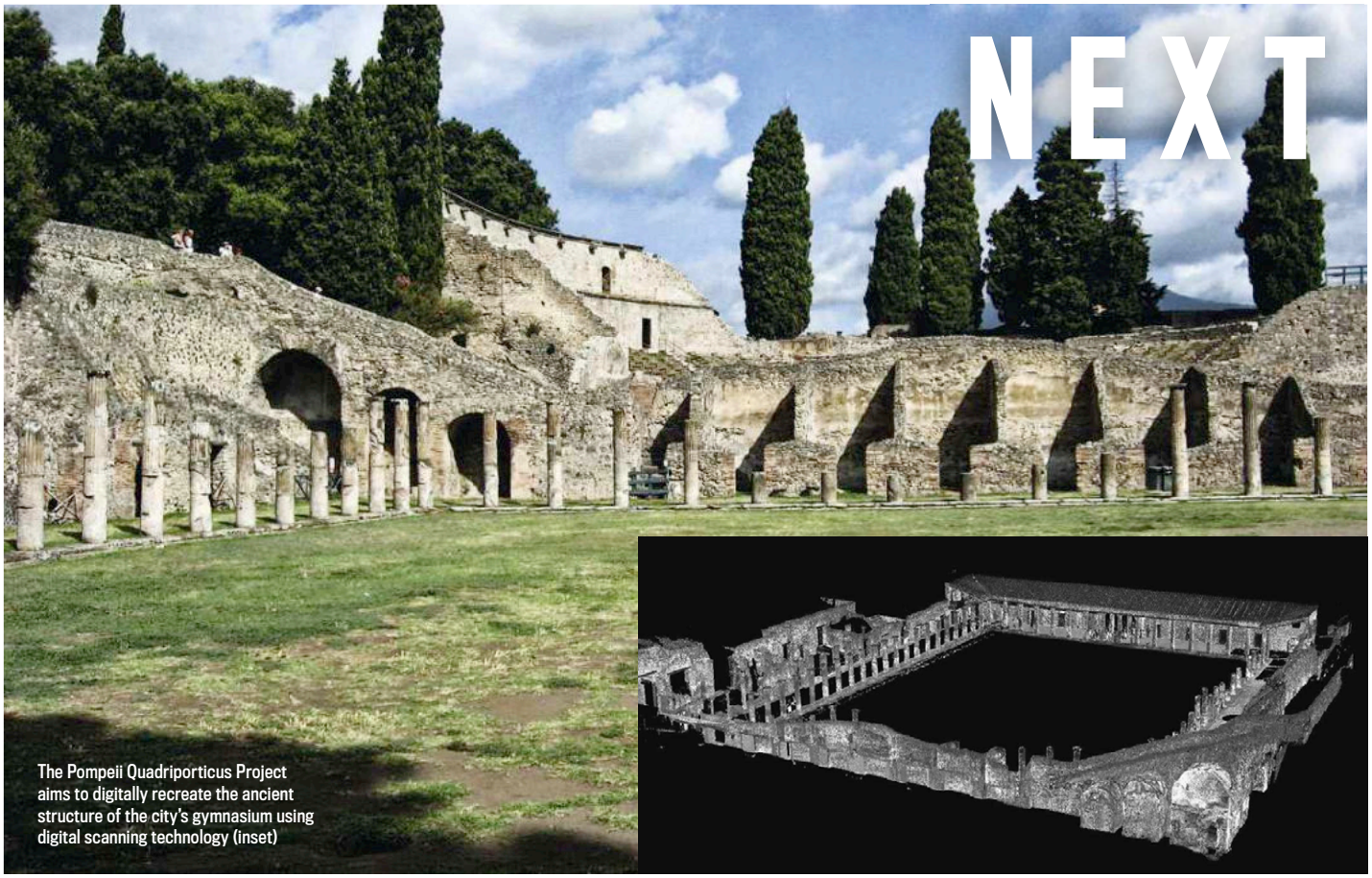
When Vesuvius does decide to perk up, however, at least we will know at once. The volcano is one of the most closely monitored on the planet and its slopes are littered with sensors designed to pick up the slightest and most fleeting signal that Vesuvius is stirring. Seismometers listen out for the tiny tremors that might indicate magma is on the move, while a network of GPS stations hunts for any ground-swelling caused by new magma making its way into the volcano's interior.

A swarm of earthquakes beneath the volcano in 1999 concentrated the minds of monitoring scientists and civil authorities alike, but the volcano soon returned to its slumber. Now all they can do is watch, wait, and plan. The problem is, what to plan for? The evacuation strategy of Italy's Department of Civil Protection assumes an eruption 10 times smaller than that of 79AD and up to a couple of weeks of prior warning in order to get people out. Others, however, think that this is too optimistic and a recipe for disaster.

"The population of the highest-risk red zone has exploded to more than 600,000"

PHOTO: THINKSTOCK; POMPEII QUADRIPORTICUS PROJECT X2

Sleeping giant: Vesuvius's crater is a tourist attraction now, but could violently erupt with little notice



The Pompeii Quadriporticus Project aims to digitally recreate the ancient structure of the city's gymnasium using digital scanning technology (inset)

POMPEII

VESUVIUS MADE A mess of Pompeii, but now it faces a second death. Walls, paintings and floors meant to last only a few decades are exposed to the feet and fingers of millions of tourists and torrential rain. Pompeii's great need is conservation, but the task is daunting. Restoring and protecting over 15,000 buildings, five acres of wall paintings and uncountable quantities of artefacts might seem impossible, but this is where developments in archaeology can help.

All teams now working at Pompeii and Herculaneum use digital scanning and recording. Not only are these techniques cost-effective, but the results are more precise than was possible with pen and paper. The American Pompeii Quadriporticus Project shows what can be done. This team of archaeologists have recorded a large rectangular open space enclosed by a colonnade backed by small rooms – probably a gymnasium – with 3D laser scanning, photogrammetry (determining the geometric properties of an object from images) and masonry analysis. The result is a convincing 3D image. Digital manipulation of the completed model will allow it to be studied in ways that are all but impossible on site. It will be a virtual archive, a form of digital conservation easier to preserve than the original.

These records can be used to print physical replicas in 3D – even full-scale models that could be opened to tourists, while the real ruins are saved for posterity. Such a replica has recently been completed of Tutankhamun's burial chamber, to stunning effect.

VESUVIUS

THE VOLCANO WILL erupt again, but when this will happen and how big the eruption will be is anyone's guess. While there is a great deal of discussion and debate within the Italian volcanological community about the scale of the next blast, the betting is that it will be similar to that of 1631. This was 10 times smaller than the 79AD explosion, but a higher population density meant that the death toll was higher, with some 4,000 people trapped in pyroclastic surges. With many more now living around the volcano, a repeat of 1631 could see a far higher death toll. It's a fear for those who have little confidence that the current evacuation plan will work effectively.

Furthermore, 1631 is far from the worst-case scenario that some volcanologists feel should form the basis of the evacuation plan. This notion has gained ground over the last year or so, following the identification of a possible active magma reservoir 8–10km beneath the surface, which appears big enough to feed eruptions on the scale of 79AD.

Even scarier, the discovery that a titanic Bronze Age eruption 3,800 years ago sent pyroclastic flows across the entire area of Naples, has taken the worst-case scenario to a whole new level. On this basis, some think that once Vesuvius shows signs of awakening, everyone within 20km of the volcano should be evacuated; a number that would reach into the millions. ■

Find out more

www.britishmuseum.org
Life And Death: Pompeii And Herculaneum runs 28 March – 29 September. Book tickets online

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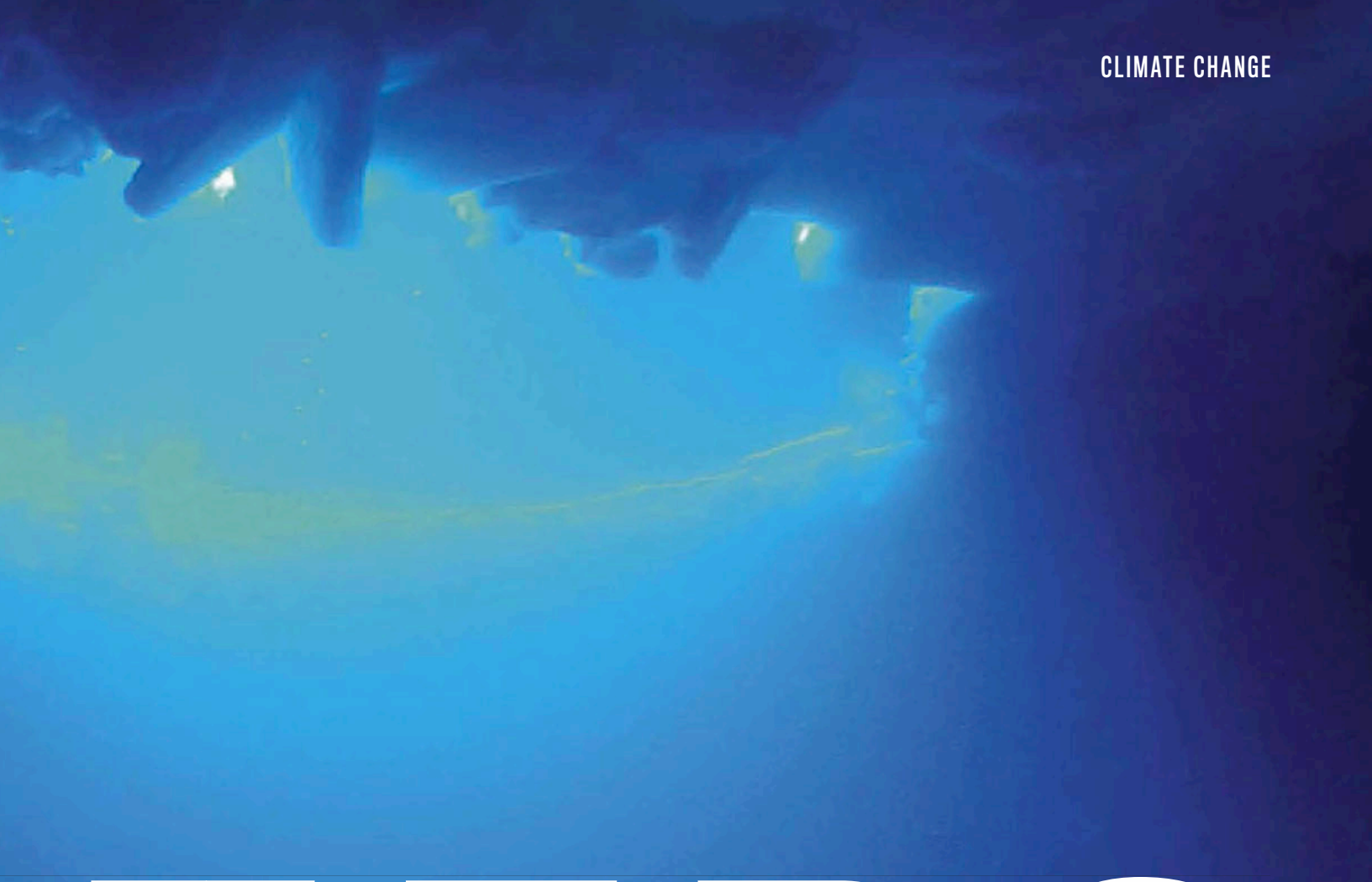
Take a virtual tour of the Quadriporticus

SUB

Under the Antarctic ice, a robotic submarine is helping reveal the impact of climate change. **Liz Kalaugher** investigates

THEY CALL IT the million-dollar boomerang. But it nearly didn't come back. Programmed to travel 20m beneath the surface of an Antarctic ice floe, this autonomous underwater vehicle (AUV) came perilously close to ramming a chunk of ice. "We received the one-minute update that it was 8m from the ice," recalls Guy Williams, project manager for the robot sub on its latest outing in October and November last year. "Then the next one came through that it was 5m from the ice and the next that it was 2m away. We had a very nerve-racking minute waiting to see if it had become trapped."

PHOTO: REUTERS



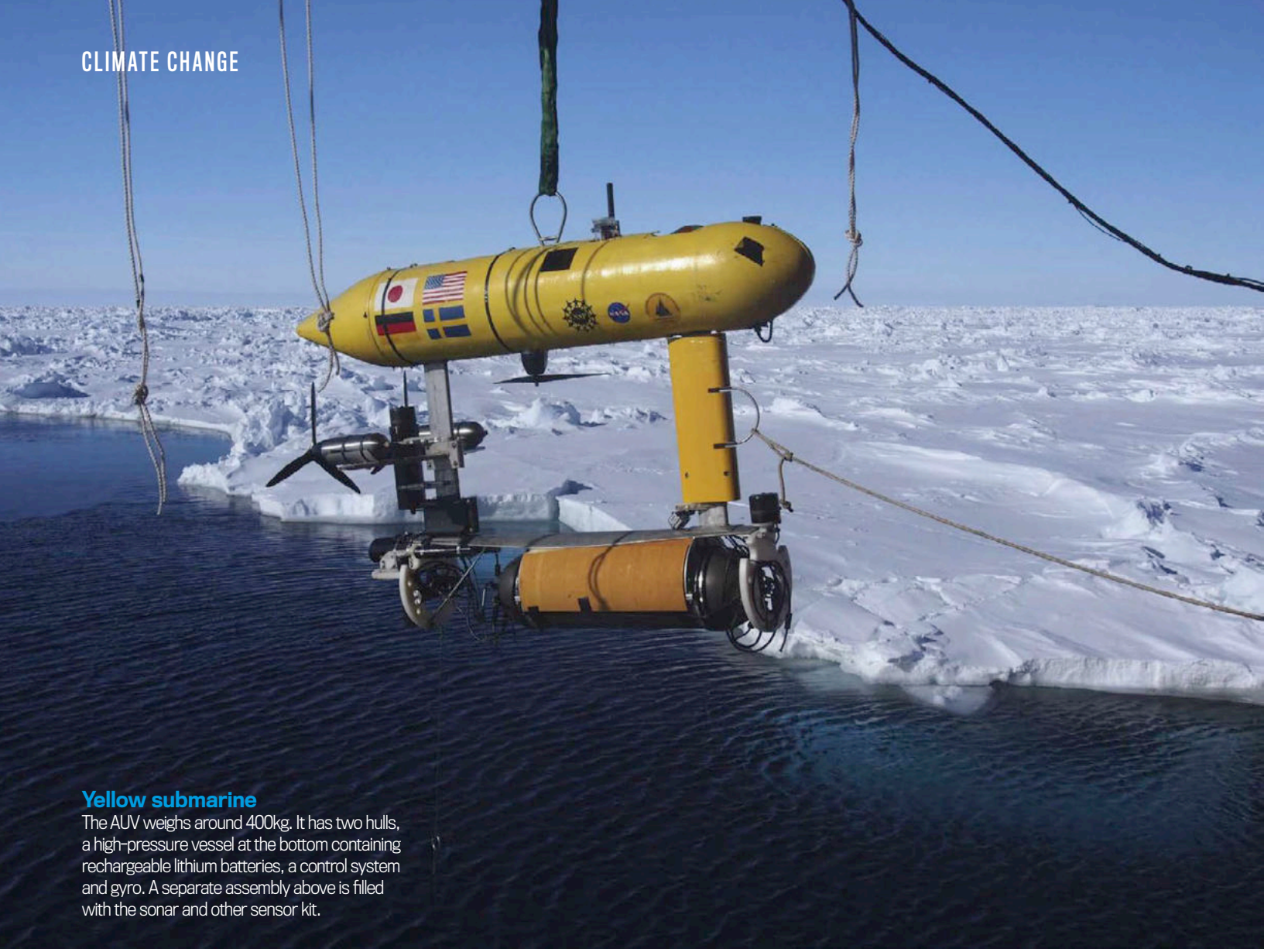
ZERO

The chances of retrieving the AUV from beneath such thick ice would have been virtually nil. But Williams and his team, part of Australia's Sea Ice Physics and Ecosystem Experiment (SIPEX-2) expedition to East Antarctica, were by no means reckless. The ICEBell project in West Antarctica in 2010, led by the British Antarctic Survey, used the same SeaBED sub but kept it 25m below the surface. This time the plan was to move closer and map the underside of the ice in more detail; from the earlier trip it seemed that 20m would be a safe distance.

So why send a $500,000 piece of kit (the nickname is a slight exaggeration) floating off potentially to its doom? In short, climate change. As temperatures rise, scientists need to check what's happening to sea ice near the Earth's poles. In the Arctic, in particular, it's not good news – September 2012 saw the lowest-ever satellite measurement of sea ice extent. The picture in the Antarctic is more mixed but in some regions sea ice is retreating even faster than in the Arctic.

The easiest way to keep an eye on such remote locations is by satellite. These can tell you about the area of ice, but it's early days for measuring thickness from space. That's where the AUV, developed at the Woods Hole Oceanographic

This autonomous submarine travelled a total distance of 26km to map the undersides of ice floes in Antarctica



Yellow submarine
The AUV weighs around 400kg. It has two hulls, a high-pressure vessel at the bottom containing rechargeable lithium batteries, a control system and gyro. A separate assembly above is filled with the sonar and other sensor kit.

Institution (WHOI) in the US, comes in. By sending it beneath the ice, the team was able to field-test how much the surface can reveal about the depth below. Ultimately, the goal is to cross-check sub and satellite data.

That's important because, as the sub's three-dimensional ice underside maps show, ice floes can have a pretty varied structure. At the mercy of the wind and ocean currents, they continually form and reform, crashing into each other like two pavlovas. Where they hit, a pressure ridge can form on the surface, along with a deep keel below. This was a contributing factor to the near miss – the rubble field on top of the floe gave little hint of the 19m-thick ice feature beneath.

What the SIPEX-2 trip did prove, in conjunction with ICEBell, is that SeaBED can map ice cost-effectively in both East and West Antarctica. Larger AUVs can cost millions of dollars; Williams reckons this sub is advantageous because "while you don't plan to lose an AUV, in this case it's not going to destroy budgets".

"There's a direct link and you can drive the AUV from a keyboard like a computer game"
Guy Williams, project manager

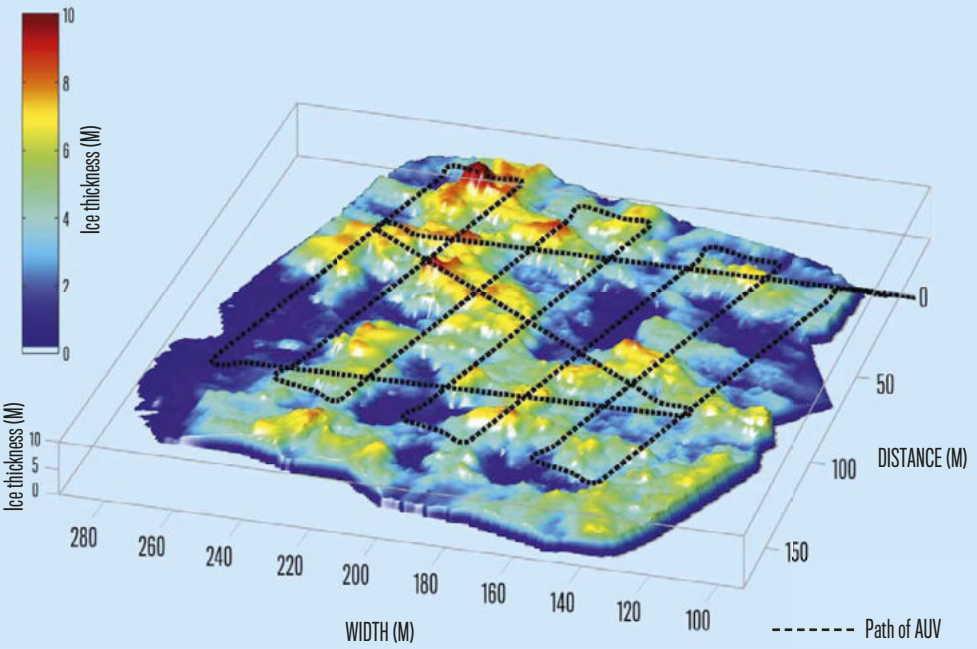
PHOTO: WENDY PYPER X2, JAN LIESER, AUSTRALIAN ANTARCTIC DIVISION

The sub is 'driven' by a team of three – a robotics engineer, a mechanical engineer and overall project manager Guy Williams (back right)

GOING WITH THE FLOE

Working from a ship is not easy, especially when everything around you is moving. By mooring the icebreaker Aurora Australis to the edge of an ice floe, Williams and colleagues provided a fixed point to help the AUV navigate. Then they trekked off onto the floe, which was typically the size of a couple of football fields, to drill holes through the ice and drop two acoustic transponders into the ocean. Together with another transponder attached to the stern of the ship, these made a reference triangle for the sub to pilot itself inside. Launching the AUV was simply a matter of lowering it into a small

Ice breaker
Moored to the ice floe, the good ship Aurora Australis provides a floating base for operations, with the AUV lowered into the sea from the back.



Upside-down mapping
The ice underside map shows a terrain like Earth's flipped upside down, with peaks and low-lying areas like the mountains and lakes on land. The AUV travelled along a preset 'lawn mower track' over an area a few hundred metres square. Red indicates a thick section of ice.

area of open water at the back of the ship. "At the surface there's a direct radio-antenna link and you can drive the AUV from a keyboard like a computer game," explains Williams.

Once in position and instructed to start its mission, the sub became truly autonomous. In a pre-programmed route, it headed to a depth of 20m and set off towards the ice. Underneath the floe, the SeaBED's Doppler velocity log locked onto the bottom of the ice, so the sub could navigate even if the floe was moving at a different rate to the ocean. The AUV travelled along a preset track over an area a few hundred metres square, bouncing sound waves (known as swathe multibeam sonar) off the bottom of the ice to measure its position, and collecting swathes of data 20m wide.

Next the scientists cross-check ice data from the robot sub with surface measurements taken by a laser scanning system and snow-depth probe, matching up data locations using GPS. Then they compare their results to longer-range surface measurements taken with helicopter-mounted sensors, and finally to satellite observations.

Unlike conventional single-hulled, torpedo-like AUVs, which travel hundreds of kilometres at a speed of 1-2 metres per second, this robot sub floats at around 30 centimetres per second. With one vertical and two horizontal thrusters, it can "stop and turn on a dime", says Williams.

Scanning one floe takes between four and five hours. Unusually for the Earth sciences, the data is largely ready within two or three hours of collection. That meant Williams and his team could provide a map of the sub-ice environment to the 60-odd other scientists on board studying sea ice physics, algae and shrimp-like creatures known as krill.

In the later stages of its planned seven-week cruise, the Aurora Australis struck very thick, heavily-deformed ice, leading to a two-week extension to the trip and the end of AUV missions. That meant no more ice maps to add to the four floes already bagged. "Part of working in Antarctica is getting stuck in the ice," says Williams. "We always want more but what we got was still very attractive. We won't go back down into the sea ice without an AUV ever again. It's been a game-changer." ■

The Aurora Australis struck thick ice at the end of its mission, leading to a two-week extension to the trip

LIZ KALAUGHER is editor of IOP Publishing's environmentalresearchweb (http://environmentalresearchweb.org)

Find out more

BBC Science: Antarctica
www.bbc.co.uk/science/earth/water_and_ice/antarctica

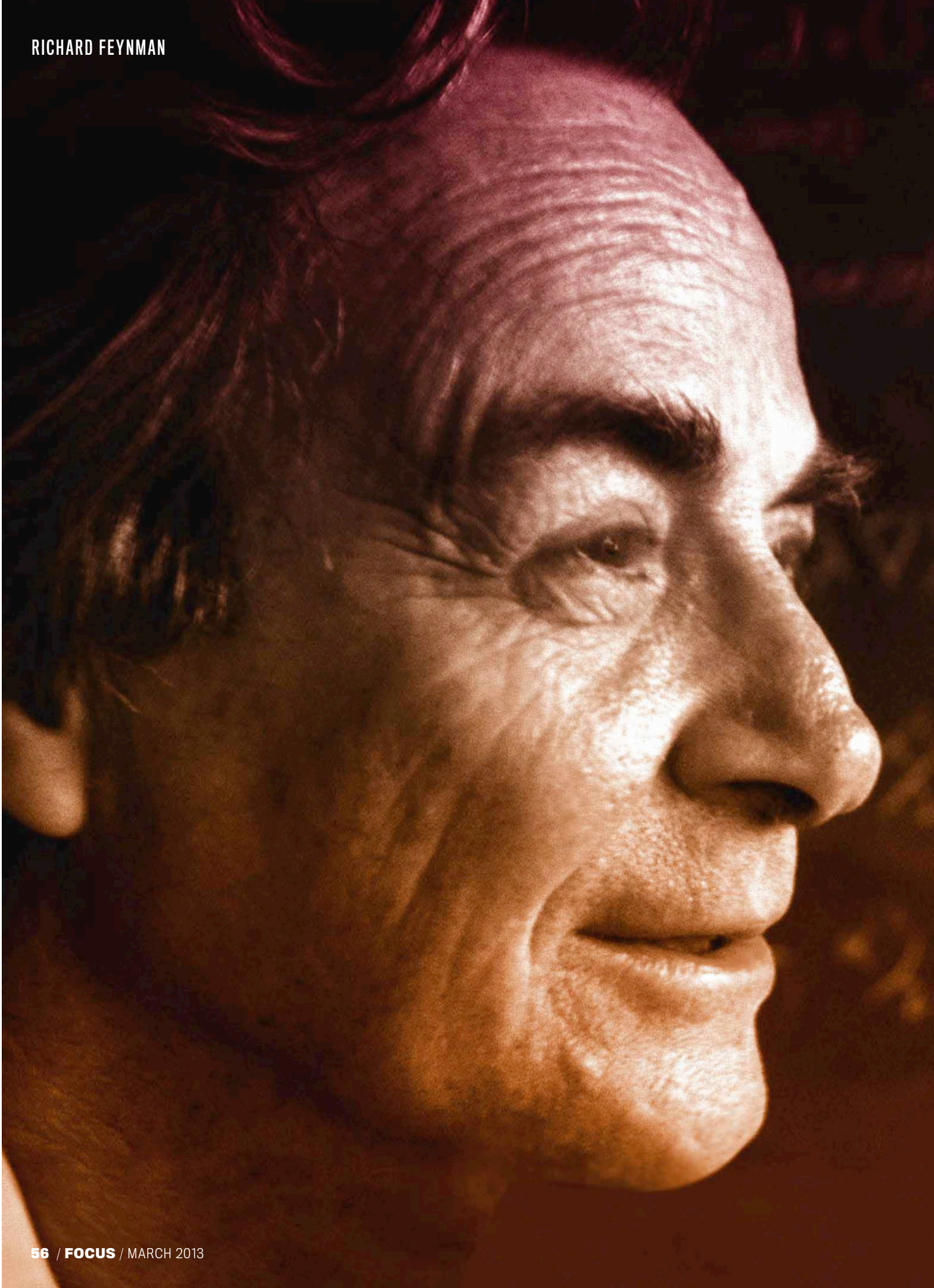


PHOTO: CORBIS

THE GENIUS OF RICHARD FEYNMAN

Twenty five years after the death of the brilliant theoretical physicist, **Dr John Gribbin** takes a look at his greatest scientific achievements

RICHARD FEYNMAN WAS not your typical scientist. The American theoretical physicist had a penchant for picking safes, was a capable bongo player and made no secret of his fondness of strip clubs where he scribbled equations on napkins between performances.

But Feynman wasn't just a wacky academic, generating inconsequential theories. Now, 25 years after his death on 15 February 1988, *Focus* takes a look at his incredible scientific legacy. He's helped us to understand the inner workings of atoms, inspired a whole branch of technology and provided an insight into the earliest moments of the Universe.

Whatever he did, Feynman did in his own way. Called on to investigate the Challenger Space Shuttle disaster, he used his charm and scientific logic to get to the bottom of what went wrong. It's a story that will soon be told in a BBC Two drama.

Feynman's philosophy towards his work was summed up best when he said: "Study hard what interests you the most in the most undisciplined, irreverent and original manner possible." It's a philosophy that led him to touch many fields of science.

FEYNMAN FACT

Late in life, Feynman became obsessed with the idea of visiting Kyzyl, a city in Tuva, Russia, solely because its name had no vowels. He died before he could make it.

QUANTUM ELECTRODYNAMICS

In his late 20s, he developed a theory that spans much of physics and also reaches into the heart of chemistry

NOT LONG BEFORE his 30th birthday, in early 1948, Richard Feynman spoke at a meeting of some of the brightest minds in quantum physics in Pocono, Pennsylvania. Teaching theoretical physics at Cornell University at the time, he presented his early ideas on quantum electrodynamics (QED) – a theory that describes all interactions involving charged particles. Since the behaviour of atoms and molecules depends on interactions between these particles – things such as electrons and nuclei – QED explains *all* of chemistry.

The trouble was, nobody understood what Feynman was getting at because he used a new approach to depicting the behaviour of subatomic particles and which later developed into his famous 'Feynman diagrams'.

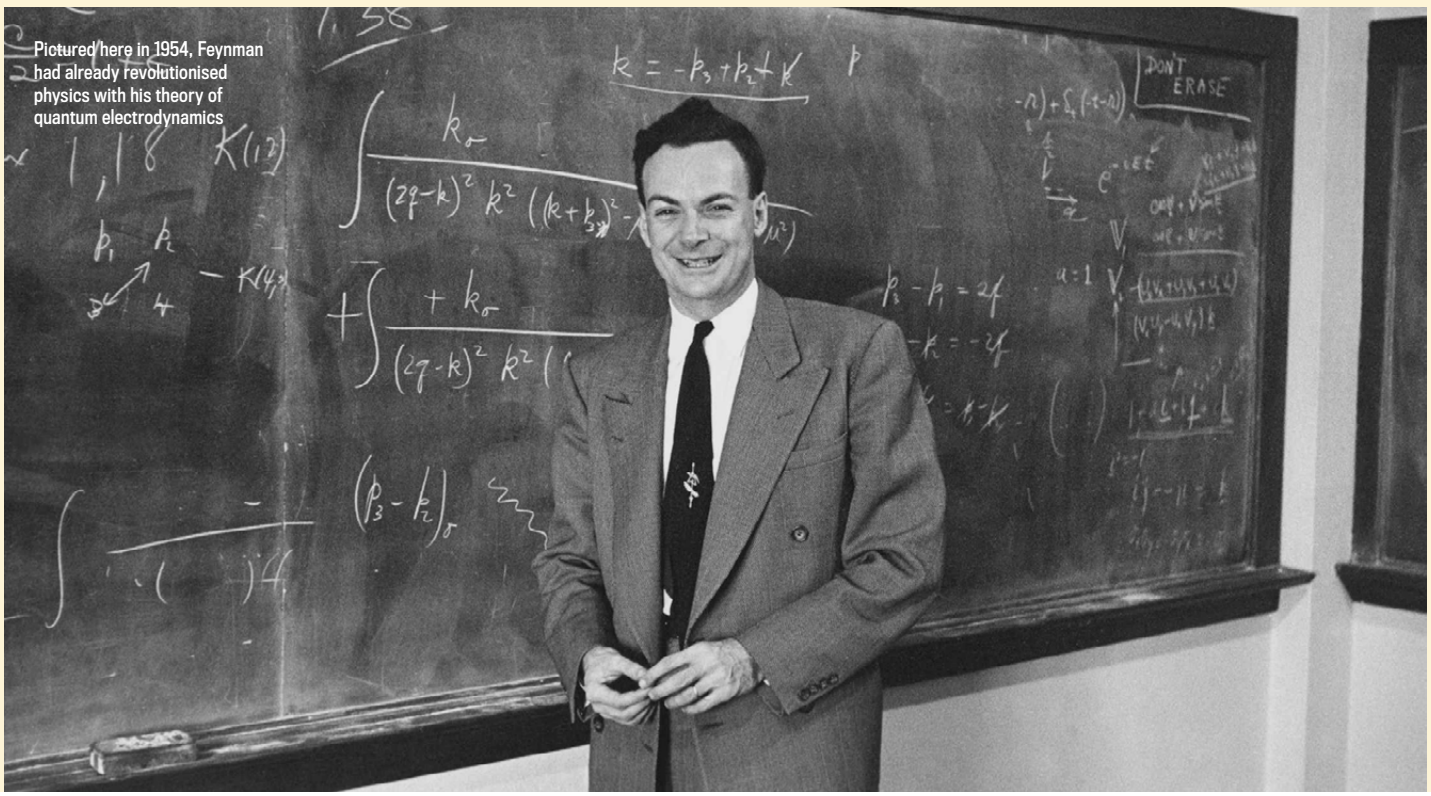
At the same meeting at the Pocono Manor Inn, Harvard physicist Julian Schwinger presented another version of QED. Again, no-one understood it – this time because it was so mathematically complicated. And soon after, news came from Japan that another physicist, Sin-Itiro Tomonaga, had independently developed a third version of QED.

Other physicists remained baffled until British-born Freeman Dyson published a paper in 1949 on *The Radiation Theories Of Tomonaga, Schwinger And Feynman*, which showed that all three theories were equivalent to one another and, crucially, made it clear that Feynman's version was the easiest one to work with. Dyson had translated Feynman into language that ordinary physicists could understand, and Feynman's own complete account of QED was published in three major papers over the next three years.

The impact of QED can't be overestimated. It explains everything that isn't explained by gravity. It's also the most accurate theory ever tested by experiments on Earth. One of these involved measuring a property known as the magnetic moment of the electron – a magnetic effect caused by an electron's spin. Feynman was fond of pointing out that the agreement between the theory and this experiment is better than 0.00000002 per cent – equivalent to measuring the distance from Los Angeles to New York to the thickness of a human hair.

Tomonaga, Schwinger and Feynman shared the Nobel Prize for physics in 1965, but by then Feynman's version of QED had long been established as *the* way to tackle problems in quantum electrodynamics. At a meeting of the American Physical Society soon after, Dyson said: "We have the key to the Universe. Quantum electrodynamics works and does everything you wanted it to. We understand how to calculate everything concerned with electrons and photons. Now all that remains is merely to apply the same [ideas] to understand weak interactions, to understand gravitation and to understand nuclear forces."

He was mostly right. The theory of weak interactions – which explains the radioactive decay of subatomic particles – was developed as the electroweak theory, an extension of QED. The theory of nuclear forces, called quantum chromodynamics or QCD, is closely modelled on QED, as the name suggests. It explains how subatomic particles are held together to form the likes of protons and neutrons. Only gravity stubbornly refuses to come into the fold. But it is fair to say that QED has played a central role in theoretical physics. By his early 30s, Feynman had become the leading physicist of his generation.



Pictured here in 1954, Feynman had already revolutionised physics with his theory of quantum electrodynamics

PHOTO: SCIENCE PHOTO LIBRARY X2, THE CALTECH ARCHIVES

NANOTECHNOLOGY

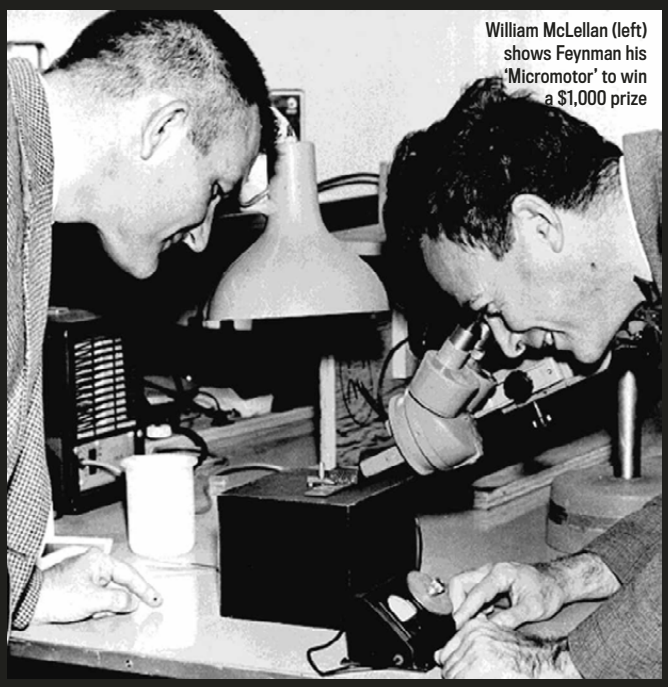
An advocate of technology on tiny scales, Feynman helped to usher in an era of microscopic engineering

FEYNMAN WASN'T 'JUST' a theorist. He was interested in practical applications of science and technology. In 1959, just after Christmas, he gave what turned out to be an influential talk to the American Physical Society on the subject 'There's Plenty of Room at the Bottom'. He threw out two challenges, each with a $1,000 prize. The first was to build an electric motor that would fit inside a cube 1/64th of an inch on each side. To his astonishment, the prize – which he paid himself – was claimed in November 1960 by the engineer William McLellan. McLellan turned up at Feynman's office at the California Institute of Technology (Caltech) carrying a large wooden box. Feynman suspected it was time to get his chequebook out when the box was opened to reveal a microscope McLellan had brought along so he could see the motor.

The second prize was for the first person to find a way of writing small enough to fit the entire *Encyclopedia Britannica* on the head of a pin. On that scale, every book ever written would fit on a pamphlet you could carry in your hand, he said. The prize was claimed in 1985 by Tom Newman, a graduate student at Stanford University, who wrote the first page of *A Tale Of Two Cities* to the required scale, actually on the head of a pin, using an electron beam.

By the mid-1990s, scientists at Los Alamos National Laboratory in New Mexico were writing whole books on steel pins measuring 25mm by 2mm, each storing two gigabytes of information in a permanent form. This, rather than vulnerable electronic media, is the best way to preserve information for posterity.

But Feynman's key insight was not so much the hardware he envisaged, but the emphasis on storing information as efficiently as possible. Today, physicists manipulate individual atoms and electrons as 'on-off' switches to store information in binary code, the ultimate expression of what Feynman envisaged more than half a century ago.



William McLellan (left) shows Feynman his 'Micromotor' to win a $1,000 prize

QUANTUM COMPUTING

Feynman envisioned harnessing the strange world of quantum physics to create super-powerful computers

A quantum computer would be far more powerful than its classical equivalents used today

THIS IS A hot topic today, with the prospect of building machines as far in advance of classical computers as classical computers are in advance of the abacus. At a meeting at the Massachusetts Institute of Technology (MIT) in 1981, Feynman gave a talk titled 'Simulating Physics With Computers', in which he tackled two questions: is it possible to simulate quantum physics with a quantum computer – a computer that harnesses the power of atoms to process data? And, is it possible to simulate quantum physics with a classical computer?

He gave an example of how a 'universal quantum simulator' might work, and said: "I therefore believe it's true that with a suitable class of quantum machines you could imitate any quantum system, including the physical world." This is the root of the idea that our whole Universe could be a simulation running inside a computer (see p43 for more on that).

Feynman thought further about computation in general and about quantum computers in particular. He gave a course on computation at Caltech from 1984-86 and another in Anaheim in California in 1984, in which he described the basis of a quantum mechanical computer. In that talk, he came up with another of his memorable comments. "It seems that the laws of physics present no barrier to reducing the size of computers until bits are the size of atoms and quantum behaviour holds dominant sway," he said.

Such machines have now been built. But he never seems to have put two (from his 1981 lecture) and two (from his 1984 lecture) together and realised that such a computer would be fundamentally different from a classical computer not just in terms of its physics, but in terms of the kinds of problem it could solve.

WORLDS WITHIN WORLDS

Richard Feynman was the originator of the idea of particles existing inside other particles

IT IS A cornerstone of the standard model of physics that entities such as protons are not point-like particles, but contain other entities known as quarks. The standard model is the theory concerning the electromagnetic, the weak and the strong nuclear interactions. Quarks interact with one another by exchanging gluons, equivalent to the way charged particles interact by exchanging photons. But it is not always appreciated that this whole package of ideas about particles within particles was developed by Feynman in the 1960s, at a time when the existence of quarks was regarded as a wild idea.

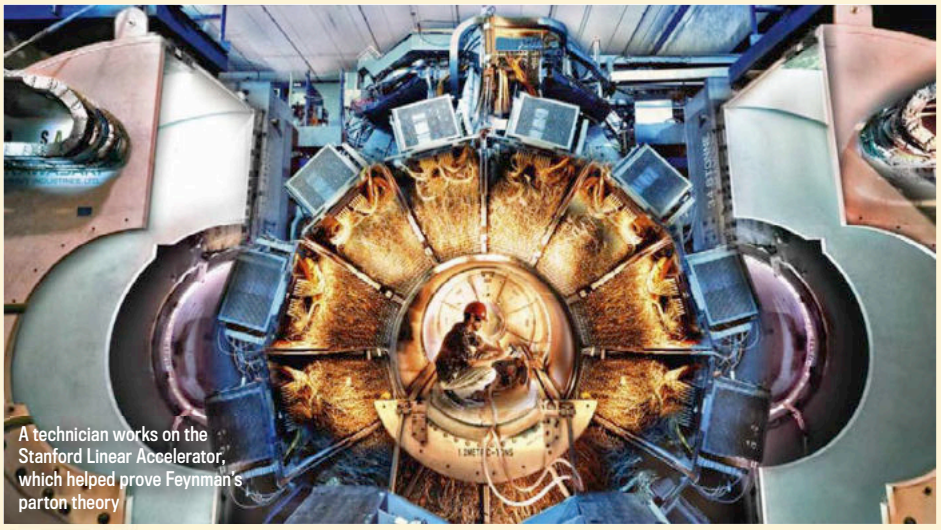
Feynman used the term 'partons' to include what are now known as quarks and gluons, and he was instrumental in encouraging the experiments that proved the existence of quarks. American physicist Murray Gell-Mann, Feynman's sometimes bitter rival and the man credited with the idea of quarks, used to sneer at what he referred to as Feynman's 'put-ons'. Like Feynman's diagrams, this made particle physics accessible even to people without the brain power of a Feynman or a Gell-Mann.

But Feynman had the last word. His ideas were picked up by experimenters at the Stanford Linear Accelerator Center (SLAC), a new particle accelerator built near the university's main campus. In August 1968, Feynman visited SLAC and looked over its data. He quickly realised that the results matched the predictions of his parton theory and his ideas spread through the team like wildfire.

Further experiments inspired by this proved the existence of quarks and also of the other kinds of partons predicted by Feynman. The experimenters – Jerome Friedman, Henry Kendall and Richard Taylor – received the Nobel Prize in 1990, two years after Feynman died.

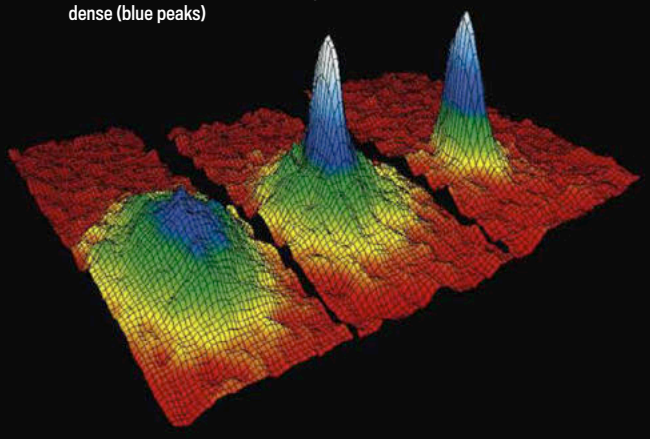
FEYNMAN FACT

Fascinated by picking locks, while working on the atomic bomb project at Los Alamos in the 1940s he would open the locked filing cabinets, simply to prove that documents within weren't secure.



A technician works on the Stanford Linear Accelerator, which helped prove Feynman's parton theory

PHOTO: STANFORD LINEAR ACCERLERATOR, SARAH REINGEWIRTZ/SXCITY, SCIENCE PHOTO LIBRARY, NIST/JILA/CU BOULDER



Research into atoms approaching the super-cooled state of a superfluid shows they become, from left to right, less dense (red areas) to super dense (blue peaks)

SUPERFLUIDITY

Feynman described the bizarre behaviour of fluids near absolute zero

WHAT DO YOU do after you have solved the puzzle of quantum electrodynamics? That would have been enough for most physicists, allowing them to settle down into a quiet life of gentle research. But in the 1950s, still in his 30s, Feynman turned his attention to another great puzzle – superfluidity, the frictionless flow of a fluid.

He tackled the question of how and why liquid helium becomes superfluid at temperatures close to absolute zero (-273°C) in a series of 10 papers – more than he wrote on QED – published between 1953 and 1958. In doing so he devised a satisfactory theory of superfluidity.

The Soviet physicist Lev Landau independently came up with an explanation of the behaviour of liquid helium, essentially the same as Feynman's but couched in different mathematical language, and received the Nobel Prize for the work in 1962. If it hadn't been obvious by then that Feynman would soon get the Prize for his work on QED, the Nobel Committee might well have given him a share of Landau's Prize. He certainly deserved it.

FEYNMAN DIAGRAMS

His illustrations illuminate the behaviour of the tiniest of particles and show how the subatomic world works

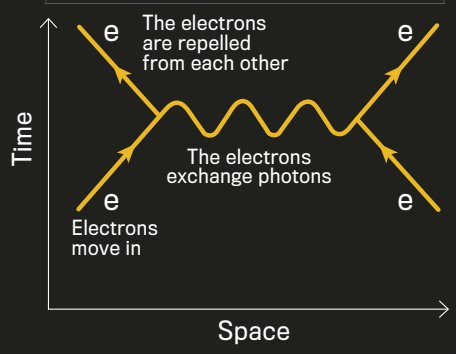
Feynman's family van was decorated with his famous diagrams (below) and is still in running condition today

THE KEY TO Feynman's way to tackle problems in quantum electrodynamics (QED) and other problems in quantum mechanics – the physics of the very small – are the diagrams that now bear his name. A very basic Feynman diagram represents two electrically charged particles – they might be electrons – which get closer together until they exchange a photon, the 'particle' of electromagnetism, before moving apart (see right). This is the QED version of the idea that like charges repel.

Many people think that this is all there is to a Feynman diagram – a kind of pictorial representation to give you an image of what is going on. But the true power of these diagrams is that each line and each meeting of lines actually represents a mathematical expression that reflects the behaviour of subatomic particles. To a trained physicist, a Feynman diagram can be read like a page of equations, but much more quickly.

There's more. For a start, the wiggly line linking the two electrons doesn't really represent a single photon, but a sum of all the possible ways the photon could have gone from one electron to the other – a so-called 'path integral'. It doesn't even specify which way the photon goes, which is why there is no arrow on it, and why physicists use the word 'exchange'.

Most Feynman diagrams are much more complicated than this simple example. An electron interacting with the field of a magnet, for example, can emit a photon and then re-absorb the same photon, called a 'virtual' photon, after it has interacted with a photon from the magnet. Or it can emit two virtual photons one after the other and re-absorb them. And so on. The calculations get harder as you go on.

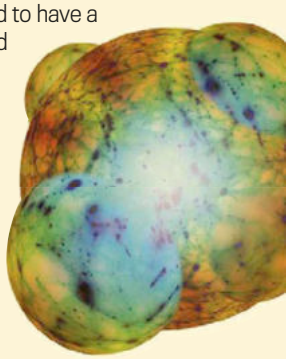


In 1975, Feynman bought a new Dodge Tradesman Maxivan. He had a personalised licence plate fitted which spelled QANTUM – only six letters were allowed at the time so there was no space for the first 'u'. He also had his beloved Feynman diagrams painted on the outside. The van was usually driven by Feynman's wife, Gweneth, as well as transporting the family on camping holidays. Ralph Leighton, the biographer, film producer and friend of Feynman, who now owns the van, says it's a symbol of his free spirit, showing his love of exploring the everyday world and of his quest to understand physics.

INFLATION

Feynman postulated how the Universe was born from nothing

IN LECTURES ON gravitation given at Caltech in the early 1960s, Feynman suggested the now fashionable idea that the Universe could have emerged literally from nothing (Big Bang pictured, inset). To do that, the total energy content of the Universe must add up to precisely zero. Feynman realised that while all the energy tied up in the form of mass is positive, the gravitational energy within it is negative, so the two could cancel each other out. For that to happen, the average density of matter in the Universe had to have a very specific value of around one atom per cubic metre – known to astronomers as the 'critical density'. But at the time, observations suggested the density was well below this. That didn't worry Feynman, who said: "The critical density is just about the best density to use in cosmological problems."



Unaware of Feynman's insight, in the 1970s and 1980s cosmologists developed the theory of inflation, which depends on the idea of 'a Universe from nothing', and 40 years after Feynman's lectures, the WMAP satellite proved that the Universe does have the critical density. Few attended Feynman's gravitation lectures, but in the audience were two students – James Bardeen and James Hartle – who went on to make major contributions to the theory of gravity. ■

DR JOHN GRIBBIN is a visiting research fellow in astronomy at the University of Sussex and the author of *Richard Feynman: A Life in Science*

Find out more

BBC TWO A drama about Feynman's investigations into the 1986 Challenger Space Shuttle disaster will be screened later this year.

BBC WORLD SERVICE *The Feynman Variations* Documentary by Brian Cox http://bbc.in/roRpWX

Richard Feynman: A Life In Science By John and Mary Gribbin (Penguin, 1998)

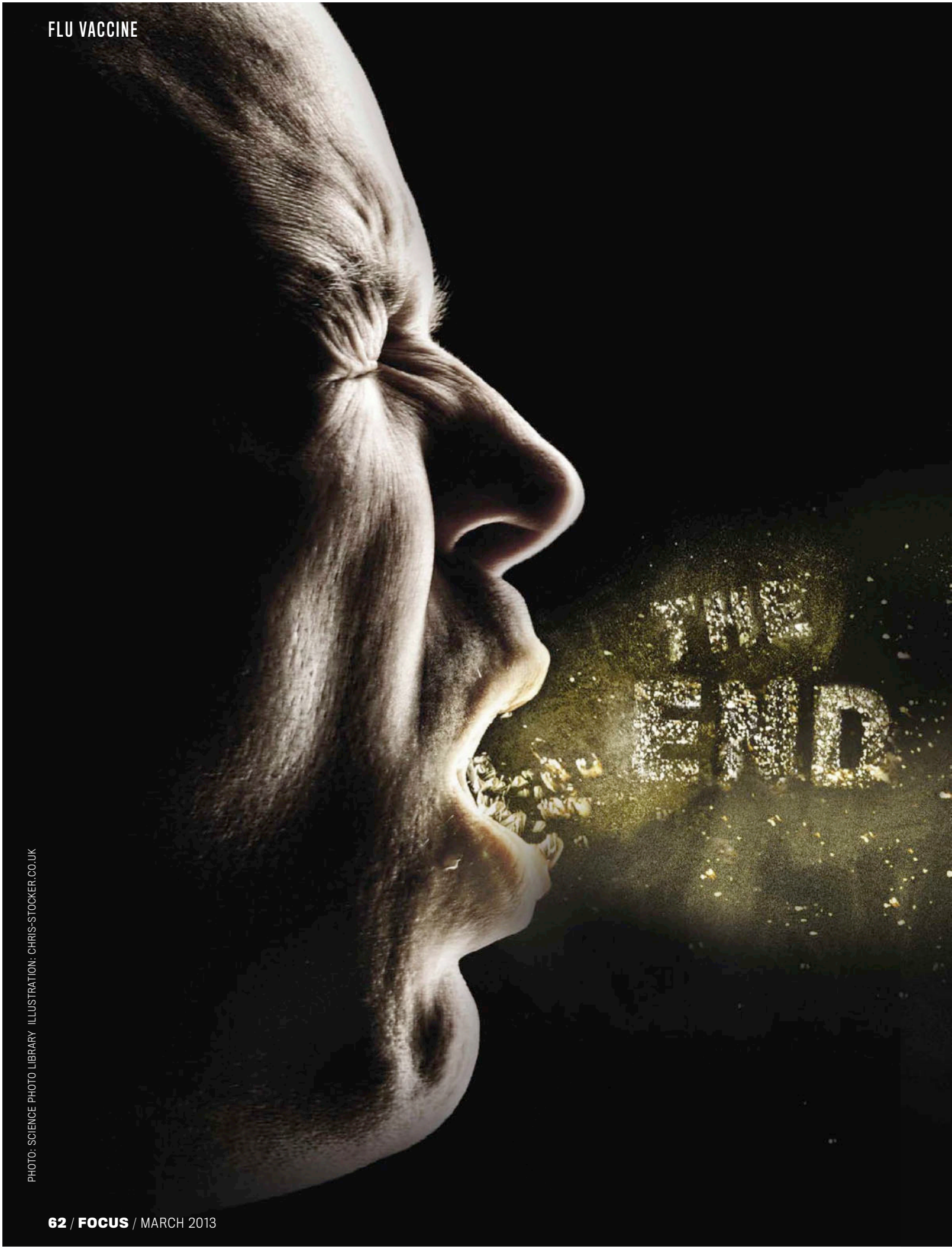
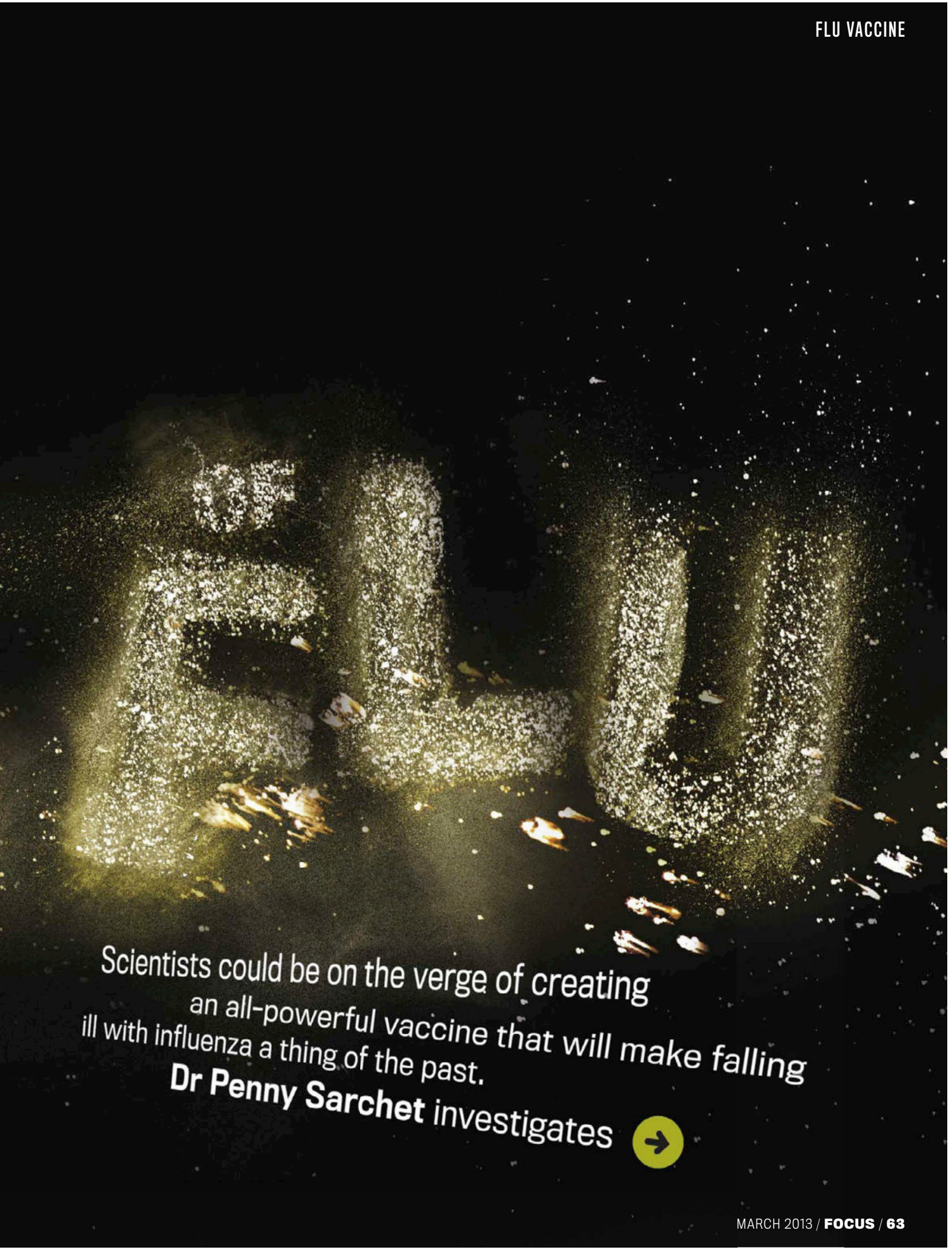


PHOTO: SCIENCE PHOTO LIBRARY ILLUSTRATION: CHRIS-STOCKER.CO.UK



Scientists could be on the verge of creating an all-powerful vaccine that will make falling ill with influenza a thing of the past. **Dr Penny Sarchet** investigates

VIROLOGISTS FROM all over the world are meeting at the World Health Organisation's (WHO) headquarters in Geneva in mid-February to discuss how best to vaccinate against a disease that claims up to half a million lives each year. This deadly virus isn't rabies – that claims an estimated 55,000 lives annually. Or ebola – that kills roughly 1,200. Nor is it any of the other viruses whose names strike fear into the minds of most people. No, the virus in question is flu.

The meeting is an annual fixture and is the time when the WHO's influenza experts decide which three strains of the virus are likely to be most prevalent next winter across the northern hemisphere. Once that's been agreed, work on a vaccine to combat these strains begins immediately. But this gathering could soon be a thing of the past with the development of vaccines effective against *all* strains of the flu virus – not just a carefully selected handful.

Around the world, labs are working towards such a 'universal flu vaccine' and the past 12 months has seen the publication of promising clinical results. Some experts believe we might be using a one-shot-beats-all flu protection in as little as five years' time.

As well as helping to combat seasonal flu, which alone leads to the loss of over six million working days annually in the UK – a universal flu vaccine would help fight pandemics. When a radically new form of the flu virus evolves, it can rapidly spread across the globe, claiming lives along the way as authorities struggle to develop a new vaccine. The virus behind the 2009 swine flu pandemic is estimated to have killed over 290,000 people. Anyone given a universal vaccine would already be protected from a radically new form of virus, so there would be no need for a scrambled response from the authorities.

"Seasonal flu kills hundreds of thousands a year thanks to its shape-shifting abilities"

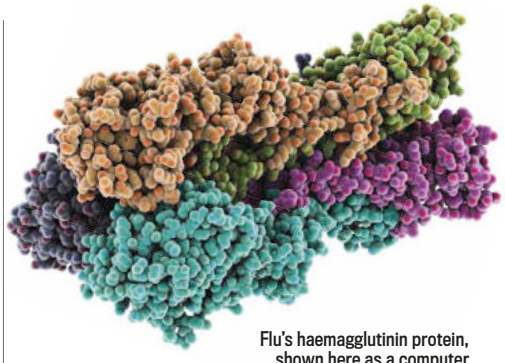
We have been using vaccines to protect against seasonal flu for over 60 years. Once the most prevalent forms of the virus have been determined, a sample of them is killed, leaving the large proteins on their surface, called haemagglutinin, intact. It's these that are the crucial part of the vaccine – stimulating the body's production of antibodies. These antibodies, also proteins, recognise a specific region of the haemagglutinin – the head – binding to it and blocking the virus from attaching to cells in the body. If a patient subsequently encounters the virus, their immune system is already primed to fight it off.

The trouble is, the haemagglutinin head, also known as the antigen, is constantly evolving thanks to genetic mutations in the virus (see 'A master of disguise' on p65). So while this year's vaccines will help your body recognise the haemagglutinin proteins of this year's variants, by next year the most abundant flu viruses will have subtly different haemagglutinin heads. These slight changes in haemagglutinin structure are called antigenic drift and mean the virus can largely escape the clutches of your antibodies.

And while seasonal flu kills hundreds of thousands each year thanks to its shape-

FLU'S MONTHLY RISE AND FALL

The rate of flu cases in Scotland reflects those seen across the Northern Hemisphere

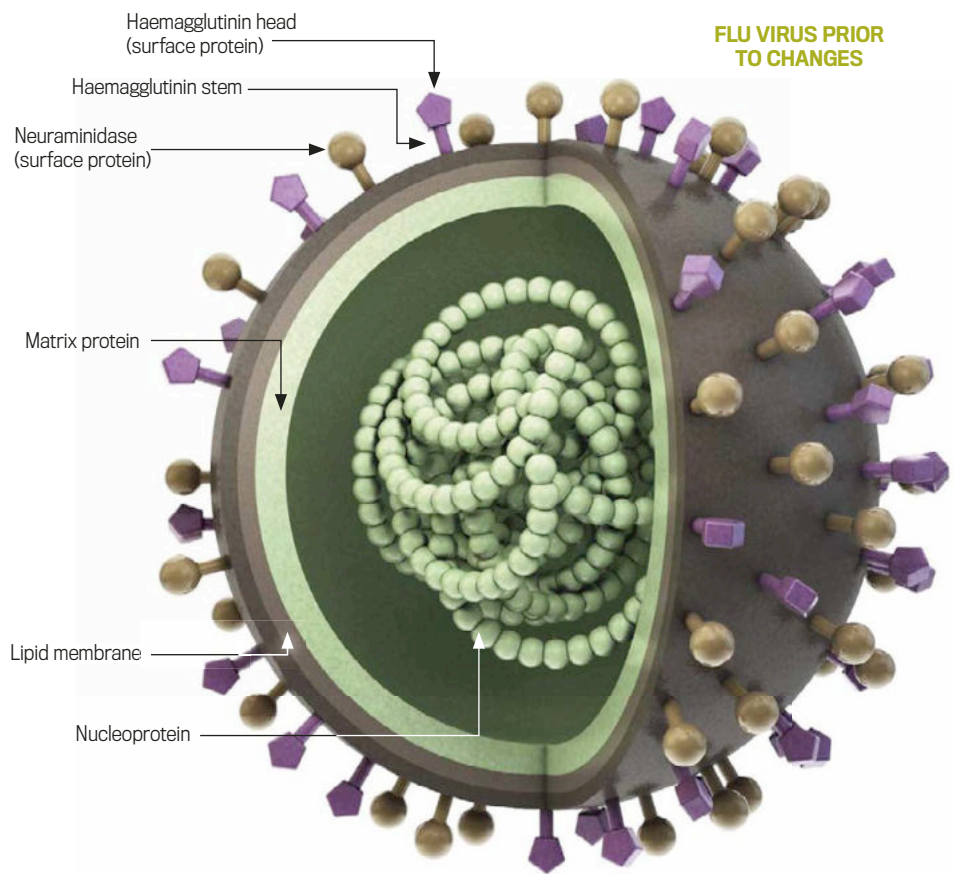


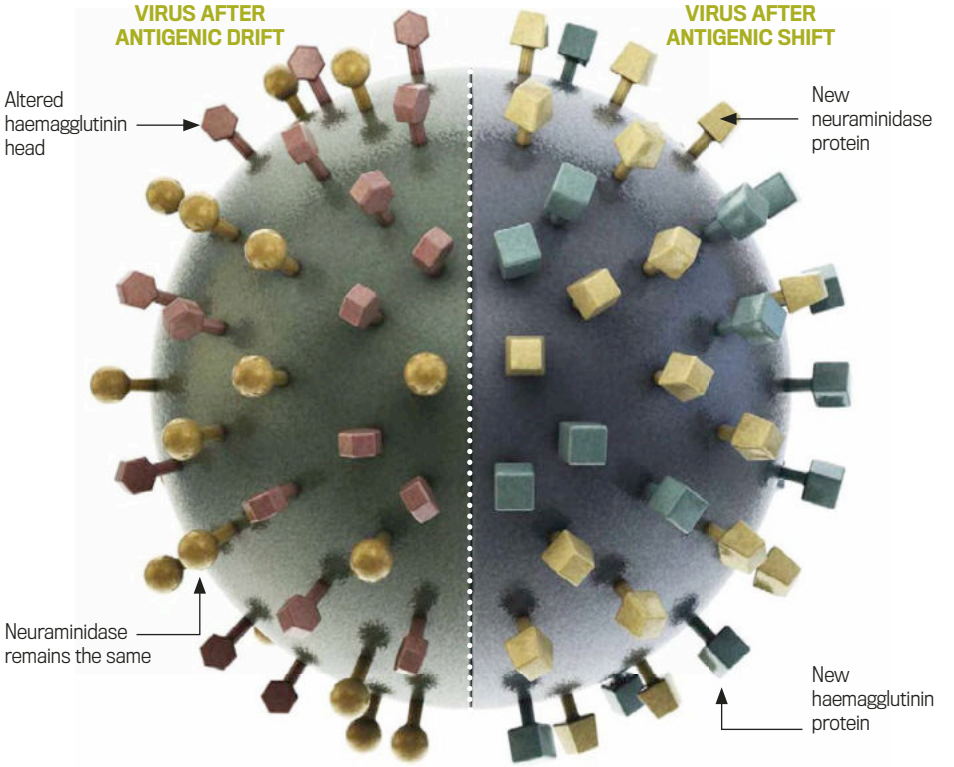
Flu's haemagglutinin protein, shown here as a computer model, is a key battleground in the fight against the virus

PHOTO: SCIENCE PHOTO LIBRARY ILLUSTRATION: MAGICTORCH

A MASTER OF DISGUISE

Flu can change form to baffle immune systems





shifting abilities, a pandemic has the potential to kill millions. "There are many influenza viruses circulating in aquatic birds, pigs and other animals. Pandemics happen when they exchange genes and jump to humans," says Professor John Schrader, of the University of British Colombia in Canada.

This process is called antigenic shift and it's bad news. Whereas seasonal flu is caused by *slight* changes to the haemagglutinin head, making it fairly easy for the antibodies to mount a response and mitigate the infection, pandemic flu arises when viruses change whole proteins. This makes them even tougher for the immune system to recognise. "The lofty goal is to design a vaccine that protects you life-long from seasonal influenza and pandemic influenza," says Schrader, "but a boost every five years would be acceptable."

EARLY SUCCESS

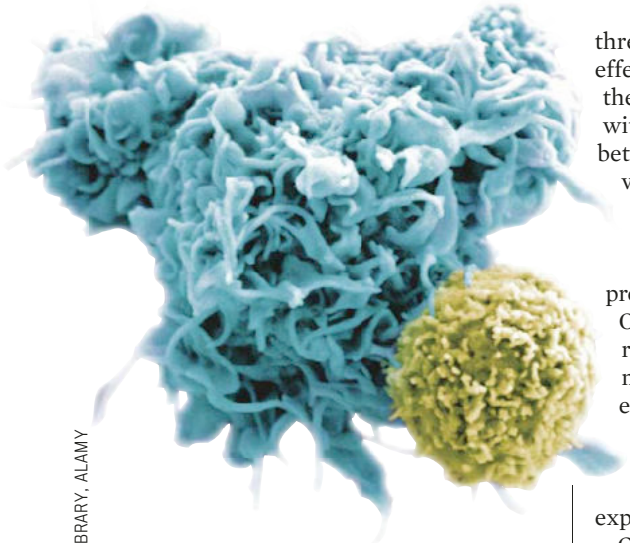
At the University of Oxford, Professor Sarah Gilbert has made significant strides towards this goal, carrying out a successful – albeit small-scale – early trial of a universal flu vaccine.

When under attack, the body not only targets pathogens using antibodies, it also uses a type of cell found in the bloodstream called T cells. These identify cells that have been infected by a virus and destroy them. Gilbert's vaccine boosts the number of these T cells. "We all have T cells specific for an influenza virus after we have recovered from flu, and those T cells can prevent us becoming ill the next time we are exposed to the same virus," explains Gilbert.

Gilbert's team are working to produce a vaccine that does not train the T cells to recognise the changeable haemagglutinin head. Instead, the T cells are trained to recognise two other, less changeable, proteins called the nucleoprotein (NP) and matrix protein (M1).

Gilbert's team, based in Oxford and Southampton, engineered a

People wait to receive information about the swine flu pandemic at a hospital in Pune, India, in 2009



A T cell (yellow) attaches itself to a dendritic cell (blue); viruses like flu are presented to a T cell by dendritic cells, before the T cell produces antibodies to fight it

PHOTO: PRESS ASSOCIATION, SCIENCE PHOTO LIBRARY, ALAMY

virus that can infect cells but cannot replicate, so the volunteers involved with the trial would not get sick with it. This virus carried the influenza M1 and NP proteins, training T cells to recognise and destroy any cells in the body that are infected with a virus carrying these two proteins. Flu viruses are grouped into three types, A, B and C. Gilbert's vaccine is effective against type A viruses. "Because the parts of the virus that we are targeting with this vaccine are very well conserved between all influenza A viruses, one vaccine can in theory protect us against all influenza A viruses," says Gilbert.

In July 2012, Gilbert and her colleagues published results from a preliminary clinical trial, carried out in Oxford. Her team found that volunteers receiving this vaccine do produce more T cells and when 11 of them were exposed to flu – given a dose of a flu virus up their noses while they were held in quarantine – only two got sick. Of the 11 unvaccinated volunteers exposed to the same virus, five fell ill.

Gilbert's team's next priority is to test a tweaked version of the vaccine to see whether it can maintain the T cells at protective levels for longer periods of time. Even then, Gilbert says it would not be for life – it would need to be repeated at regular intervals. Perhaps every five years.

Across the Atlantic, Schrader's team is taking a different tack – trying to train our antibodies to become defenders against all types of influenza A virus. This work was inspired by an observation made during the first flu pandemic in more than 40 years.

"The vaccine may be ready for hospitals and doctors' surgeries in 10 years"

"I found in August 2009, during the swine flu pandemic, that people infected with swine flu H1N1 made cross-reactive antibodies that could bind to avian H5N1 influenza," says Schrader. "That was the first observation that humans could make cross-protective antibodies against many types of influenza viruses."

Instead of targeting the haemagglutinin head, these all-powerful super antibodies recognise the stem region of this protein. Compared to the head, the stem is less changeable, remaining similar between different strains.

Schrader believes the key to stimulating production of these cross-protective antibodies is creating vaccines using viruses that have changed more dramatically than just by antigenic drift.

71-167

billion dollars is the estimated annual cost of influenza epidemics to the US economy

"My idea is to make influenza vaccines from an antigen-shifted virus that is not circulating in humans," explains Schrader. He believes that if we did this, it would arm the immune system with a more effective means to recognise flu virus invaders, giving protection across all strains of influenza A.

So far, Schrader says he has encouraging data from animal experiments. He believes that if his ideas are correct, the vaccine may be ready for hospitals and doctors' surgeries in 10 years.

ENCOURAGING SIGNS

The treatments being developed by Gilbert and Schrader are just two of a number of potential universal flu vaccines. Another group of researchers, led by Dr Ian Wilson of the Scripps Research Institute in California, has developed antibodies that can block not only type A influenzas, but type B too.

But it's not all good news. While a universal flu vaccine has the potential to save millions of lives, it will not take all the coughs, snuffles and sneezes out of winter. The common cold is caused by different groups of viruses to flu, mostly the rhinoviruses and coronaviruses, and so a universal flu vaccine would provide no protection against catching a cold. Caused by more than 200 different viral strains, the common cold presents an even trickier target. But its more dangerous relation is firmly within our sights.

DR PENNY SARCHET is an award-winning science journalist with a PhD in biology

Find out more

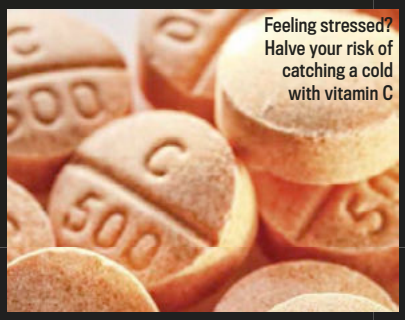
BBC RADIO 4

www.bbc.co.uk/programmes/p0129fv8

Radio 4 programme looking at how flu vaccines are manufactured

COLD HARD SCIENCE

How effective at preventing cold and flu are the remedies you can buy over the counter?



Feeling stressed? Halve your risk of catching a cold with vitamin C

VITAMIN C

TRIALS HAVE FOUND that this vitamin halves the risk of catching a cold in people who are undergoing short periods of extreme stress. Studies also suggest that it might reduce the length of colds. An Australian report published in 2004, which pooled the results of several studies, showed that vitamin C taken continually as a preventative measure reduced cold duration by 8 per cent in adults. It had no effect once the cold had started. There is no clear evidence vitamin C prevents or cuts the duration of flu.

ECHINACEA PURPEREA

A REVIEW CARRIED out for respected medical research organisation the Cochrane Collaboration in 2009 found that preparations from this flower – also known as the purple cornflower – might help reduce the severity or length of a cold. A study conducted in Germany in 2009, which included an investigator who was working for a natural remedies company, suggested that *Echinacea* extracts can interfere with flu haemagglutinin proteins. This might prevent infection of host cells by the virus.

Flower power: Echinacea messes with flu's proteins

Zinc could knock out dreaded rhinoviruses

ZINC

THIS METAL, WHICH can form part of a tablet, lozenge or syrup, appears to inhibit the replication of rhinoviruses, a common cause of colds. A review of zinc trials in 2012 for the Cochrane Collaboration found that it reduces the duration and severity of symptoms if it is taken within 24 hours of them starting. The same review says that taking zinc for at least five months reduces the incidence of colds in children. There is no strong evidence that zinc can prevent or reduce the severity of flu.

HAND HYGIENE

THE NHS IN the UK says there are three main ways to prevent flu: vaccination, antiviral medicines for particular at-risk groups, and hand washing. An Australian study in 2009 found that washing hands with soap and water or an alcohol-based hand-rub markedly reduced the concentration of H1N1 influenza virus on 14 people's hands, something that would help to stop the virus from spreading. Interestingly, washing with good old soap and water seemed to be slightly more effective at getting rid of the flu virus than an alcohol hand-rub.

Prevent the next pandemic: wash your hands!

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THE FUTURE OF GADGETS

TECH HUB

EDITED BY **DANIEL BENNETT**

THIS MONTH

ON THE HORIZON

YOTAPHONE

SMARTPHONES ARE all identical black rectangles, right? Well, think again. The YotaPhone has two screens on either side, making it unlike any other phone currently available.

It's not a gimmick, it's a smart response to how we use our mobiles now, and how they can do a lot more than just make calls. The YotaPhone's dual screens mean it can adapt depending on what you're doing. The electronic paper display on one side (as found in ebook readers like the Amazon Kindle) will be easy on your eyes when you're reading ebooks or long articles, for example, while the standard full-colour screen on the other will be ideal for viewing photos and videos.

But there's another benefit: electronic paper uses far less battery power than a colour screen. Use this screen to check your calendar, browse the web, read, check emails, write text messages and more, and the battery will last much longer. Today's big-screen smartphones sap battery life quicker than ever before, so this should be a real boon. And be honest, do you really need to read your emails and texts on a full-colour, high-definition screen every time?

YotaPhone's twin screens improve both usability and battery life

With the YotaPhone you can read ebooks on one side and watch videos on the other, saving battery life

The YotaPhone is no slouch when it comes to the standard specs, either. Both screens are 4.3 inches (10.9cm) across, and the LCD has a resolution of 1,280x720-pixels, which is HD. So your movies should look eye-poppingly good. It runs the latest version of Android Jelly Bean, so will come with the Google Now personal assistant and Google's Advanced Voice Search. A dual-core 1.5GHz processor is up there with the fastest phones around, and there's up to 64GB memory inside, too. That should store plenty of photos that you've snapped with the 12-megapixel camera on the back.

Experts believe the YotaPhone is the first true post-iPhone handset. "The iPhone defined the smartphone," says Fred Huet, managing director of Greenwich Consulting, a firm which helps mobile phone companies plan their future R&D. "But now we use our smartphones for everything from reading to the net to media consumption. So that's a clever move from Yota, to combine different needs on one smartphone."

Huet thinks we'll see far more varied devices start to emerge, beginning with the YotaPhone. "2013 will be a very interesting year in terms of devices," he says. "There have been so many advances: they're talking about integrating fingerprint technologies and flexible screens, so it'll be a lot more varied than the iPhone and we will start having much more choice. Media consumption is going mobile, and the successful smartphones are going to take this into account."

Amazon has also patented a similar device, so the YotaPhone could be the first of a whole new type of phone. This is set to be the year mobiles go large, too, with Huawei touting a 6.1-inch (15.4cm) handset, and rumours of a 7-inch (17.7cm) Samsung Galaxy Note in the pipeline. Bigger screens mean even shorter battery life, but as we've seen, the YotaPhone makes that less of an issue, and could potentially change the way we use our handsets.

So, how does that boring black rectangle of yours look now?

JOE SVETLIK is a technology news reporter for CNET and TechRadar

TECHOMETER

WHAT'S HOT

RASPBERRY PI

The credit card-sized computer that costs just £30 now comes with its own app store, making it more user-friendly and powerful than ever. Coders and tinkerers alike can create unique software like games, media players and even programs for robots, and share them on the app store with others.

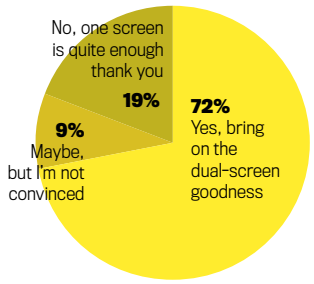
WHAT'S NOT

NETBOOKS

Seven- and 9-inch laptops are to be relegated to the history books, replaced by the tablet and ultrabook. Both Acer and Asus have announced they'll stop producing the miniature computers and focus their attention elsewhere. Netbooks are the first victims of the succes of the tablet PC, which is becoming a more viable alternative to the laptop every year.

READER POLL

Would you use a dual-screen phone?



ILLUSTRATOR: LAUREN GENTRY

EARLY ADOPTER

BILL THOMPSON

Invasion of the body hackers

The US Vice President clutches his chest in agony, collapses to the floor and dies. His pacemaker has been hacked by a terrorist, causing a fatal heart attack. While this is merely a scene from the TV drama *Homeland*, this kind of implant hacking could soon become a scary reality. This is because of the rise of sophisticated medical technologies such as pacemakers, artificial heart valves, insulin pumps, brain-controlled prosthetic limbs and, in the case of one patient, a SynCardia Temporary Total Artificial Heart.

The lives of many deaf people, for instance, have been transformed by cochlear implants, clever digital signal processors that are connected to the auditory nerve, while experiments to deliver signals to the visual cortex from cameras offer hope of giving some blind people vision. But there's growing evidence that such devices could be subject to the same sort of problems that make our PCs vulnerable to online attacks.

Last year, at a computer security conference in Melbourne, one researcher showed how to log in to a pacemaker and get it to deliver an 830V shock, while others have hijacked the controls of an insulin pump, changing the amount of the drug that would be delivered. Neither hack involved real patients, but these demonstrations should worry anyone who has an implanted medical device, or might have in future.

Part of the problem is that one obvious way to enhance medical implants is to allow remote control and monitoring, but that this is not being done

with enough concern for security. Just as computers became vulnerable when people started linking them via networks, so the hardware that we're now putting into our bodies could pose a security risk or even a risk to life. You don't want to suffer the same fate as *Homeland*'s Vice President.

These devices betray a lack of foresight and systems thinking on the part of their designers, whose security model seems to be 'Why would anyone bother hacking this?' instead of a careful, comprehensive threat analysis. The first pacemaker hack was demonstrated in 2008 – clearly nothing has changed in over four years.

In many ways, security is like accessibility. Too many organisations argue that designing a website that people with poor vision can use will add to complexity or costs and reduce usability for 'normal' people. Not only is this not true, but the cost of fixing an unusable site can be very high, because retrofitting such features after the design is locked down is hard.

The human body is a frail, imperfect machine, and we have always relied on technology, from clothes to glasses, to improve, correct or sustain ourselves. Now, like our cars, our bodies are being colonised by computers: there to improve the quality of life, or in some cases keep us alive. But we need to ensure that those designing and building these vital technologies recognise the importance of designing secure systems from the outset.

Bill Thompson contributes to news.bbc.co.uk and the BBC World Service

TELL US WHAT YOU THINK!
Should you be able to control medical implants wirelessly? Visit our forum at **sciencefocus.com/forum** and tell us what you think.

COMING SOON

3 MONTHS

HUAWEI ASCEND MATE

Stretching the definition of what you can still call a 'mobile' phone, this Android smartphone has a 6.1-inch (15.4cm) HD screen. There's brain to match its brawn, too, as it comes with a clever power management system that switches off your phone's systems when not in use to extend battery life by 20 per cent. *Huawei.com*

+ Kingston 1TB drive This is a tiny thumb drive that can store more data than most computers – which means that when it lands later this year, it'll probably cost more than most computers, too. *Kingston.com*

+ LG Super OLED TVs LG's 4mm-thick TV goes on sale next month. Unlike traditional tellies, OLEDs don't require backlight, making them much thinner. *LG.com*

6 MONTHS

NVIDIA PROJECT SHIELD

This handheld games console hopes to let gamers enjoy PC gaming graphics on a 5-inch (12.7cm) 'retina-grade' screen. In our time with the console it certainly delivered on this promise, but its success, as with any console, will depend on the strength of the games made for it. *Nvidia.com*

+ Lenovo IdeaCentre Horizon This touchscreen desktop Windows PC can be laid flat to become a tabletop computing surface. It's multi-touch, too, so several people can use it at once. *Lenovo.com*

+ Xbox The next generation of console is set to debut this summer at the E3 gaming convention, with analysts predicting they'll go on sale before Christmas. *Xbox.com*

9 MONTHS

PAPERTAB

This new paper-thin, flexible display technology could change the way we think about computing forever. A user would have several of these paper displays, all linked to a central processor. *plasticlogic.com*

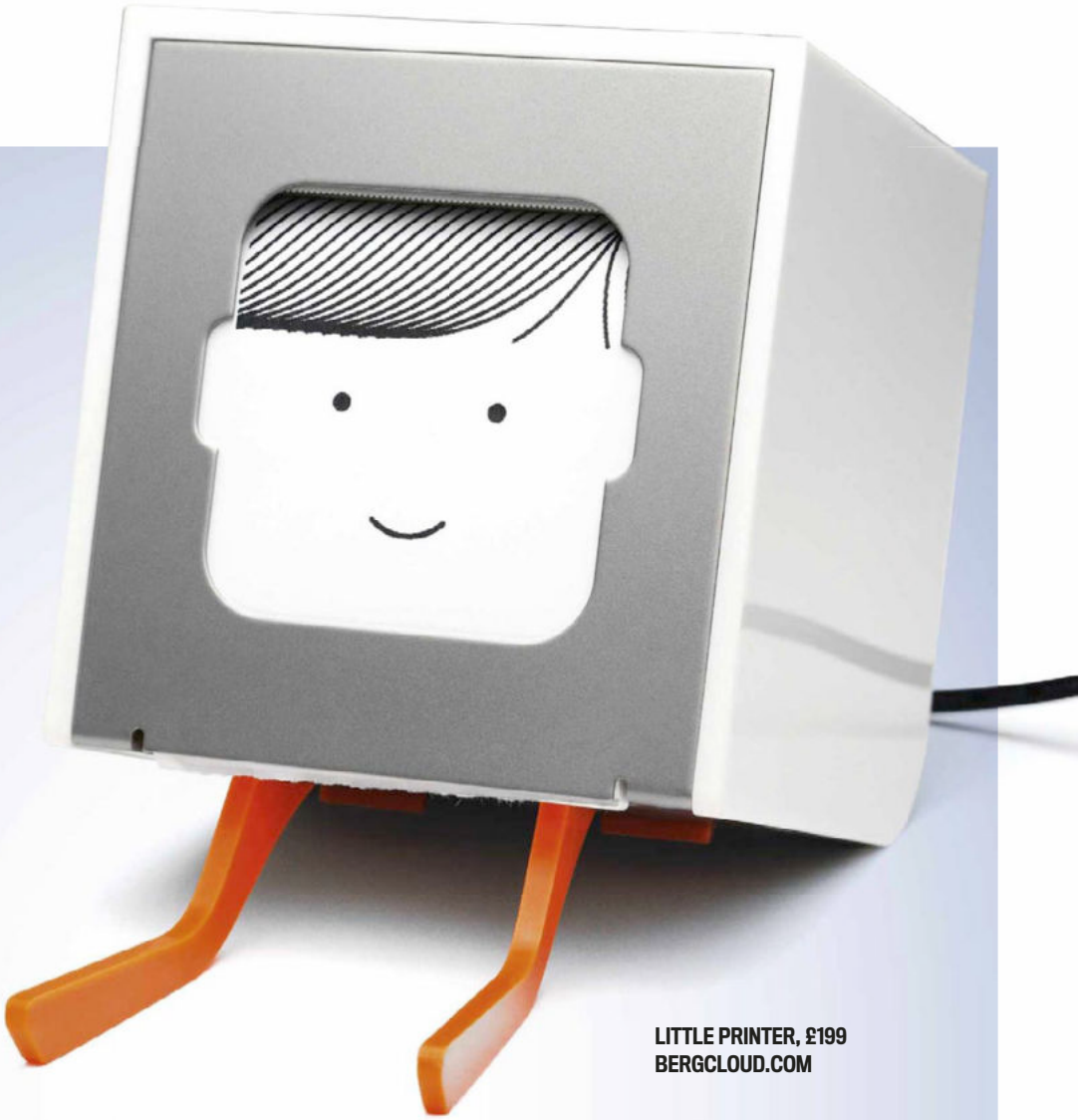
+ Vuzix M100 smart glasses This Bluetooth headset presents your phone's display on a tiny screen aimed at your right eye, so you can see map information, call info and text messages without having to get your phone out of your pocket. *Vuzix.com*

+ Samsung Galaxy S4 A flexible display? Probably not this time around, but Samsung's next smartphone is a major concern for Apple. *samsung.com*

JUST LANDED

WEB IN A BOX

Have a miniature newspaper, quizzes and more waiting on your desk every morning with the Little Printer. Daniel Bennett tests the hard copy



LITTLE PRINTER, £199
BERGCLOUD.COM

What is it?
At its simplest, this is a thermal printer, not dissimilar from the machine that prints out your receipt when you buy a pint of milk. But the Little Printer has one big difference: it's constantly connected to the web. This means that if you're out and about and come across an interesting news piece, recipe or Facebook reminder, you can hit a button on your smartphone and the Little Printer will spit out a physical copy back at home. Not only that, once you've connected it to your favourite social networks, websites and services, it'll print regular feeds. For example, you could set a daily update from a newspaper website to appear every morning at 9am.

Why would I want one?
At first, printing out reams of paper full of information that you can access on your phone might sound extravagant, but the Little Printer soon proves its worth. In practice, it works like a physical bookmark system. Say a Facebook friend invites you to an event: just hit print to have a physical reminder to hang on the fridge when you get home. You could also do this with a Wi-Fi printer, a home network and a little technical nous, of course, but no system has ever made cloud printing so easy.

Besides, the Little Printer is entirely designed and built for the smartphone. The paper is roughly the same width as your screen so there are no formatting issues, and at about the size of a Rubik's Cube it barely takes up any room. Plus, if you give your friends the printer's details, they can send messages or info straight to it.

How useful is it?
In the past, our relationship with printers has generally been one of frustration and disappointment. When you're not having to buy new ink cartridges or unclog a paper jam, you're just trying to get it to talk to your computer. The Little Printer is different.

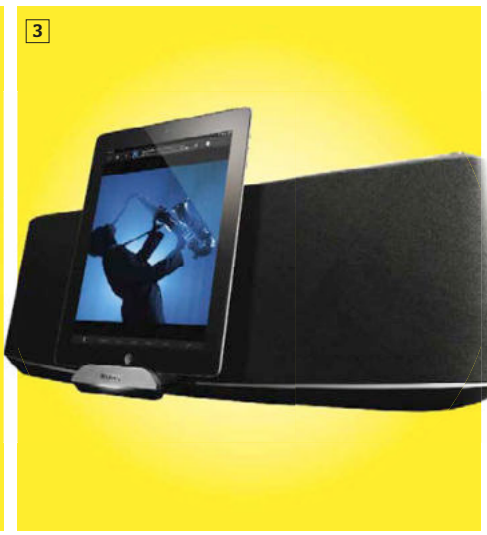
Out of the box, connecting it to your Wi-Fi network is simplicity itself. Downloading the app, setting up a series of 'publications' and printing out your first article is a joy. Connecting via the cloud creates a buffer zone so that no articles will be lost if your connection drops out, and best of all, there are no ink cartridges! Like all thermal printers, it generates letters by selectively heating special paper.

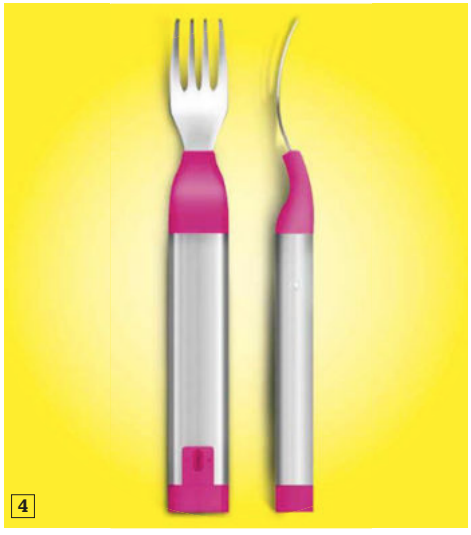
Once you're printing, the Little Printer soon becomes part of the furniture. It's most useful when employed to create physical reminders for the next day. We created running lists of stuff to do before we left the house, and became a lot less forgetful and more productive as a result.

Creating to-do lists on your phone is one thing, but there's something to be said for having a physical note waiting for you. Of course, you could just write one down, but these days you're more likely to have a smartphone to hand than a pen and paper.

The social aspect – printing off Twitter and Facebook feeds – did seem a little bizarre. These are online mediums, where people are often sharing links, photos or videos, so a printer isn't really needed.

Should I buy one?
There's no denying that having a Little Printer spewing out printed notes from your smartphone is a bit of a luxury, and at £199 it's an expensive luxury at that. At this price it's hard to justify buying a Little Printer, but if you do you won't be disappointed. This is genuinely the first printer built for the smartphone age and we hope others follow its lead.





APPLIANCES OF SCIENCE

1 HARD BEATS

This helmet for snow and board sports lovers has Beats by Dr Dre headphones built into its hardened shell, so you can listen to music while you pull your moves. It's also got an in-line microphone so you can take a call mid-descent. We're not sure how safe doing either really is, but you'll look cool... and that's half the point of extreme sports, isn't it?

PocSport Receptor Communication Helmet
pocsports.com, €220 (£182) plus P&P

2 HAPPY FEET

Protect your toes in cold weather with these remote-controlled, heated insoles. They're fitted with a thermostat which gives you two heat settings to choose from on the wireless remote. To make the battery last they simply power up to reach the desired temperature, and power down again once there. The soles are rechargeable and each pair should last up to 500 charges.

Thermacell Heated Insoles With Remote
Thermacell.com, $129.99 (£80) plus P&P

3 SPACE SPEAKERS

Sony has employed magnetically charged liquids known as 'ferrofluids' to create more accurate, louder speakers. Developed by NASA, ferrofluids are useful because they can be moved around with the use of a magnetic field, which is handy if you need to shift fuel about in zero gravity. In these speakers, Sony has replaced a speaker component called the damper with ferrofluids, reducing unwanted vibrations.

Sony XA900
sony.com, £499

4 DIET-TUNING FORK

This judgemental utensil monitors how much and how quickly you're eating using a variety of sensors built into its handle. Eat too quickly and it vibrates to warn you to slow down. Meanwhile it records exactly how many 'fork servings' you ingest overall, as well as how much you shovel in per minute. The goal is to avoid the consequences of eating too quickly, such as acid reflux and weight gain.

Hapilabs HAPIfork
hapilabs.com, price TBC

5 STICKING POINT

Attach these penny-sized Bluetooth stickers to your keys and you'll never lose them in your house again. Each sticker emits a low-power Bluetooth signal that your smartphone can detect. An app will then show you, via an on-screen radar display, how close to your keys you are. You can attach stickers to anything you like: TV remotes, your wallet or even the family pet.

StickNFind
sticknfind.com, price TBC

6 SEEING SOUNDS

If you've ever wondered how a circuit board can create artificial noises, then the best way to find out is to build an electronic synthesizer for yourself. This pocket-sized electronics kit contains all the components, including a small speaker, required to build your very own synth. It takes about an hour to put together and is powered by a 9V battery. Your first Top 20 hit is sure to follow.

DIY Synth Kit
technologywillsaveus.org, £15

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ULTIMATE TEST

SMARTEN UP YOUR HOME

The latest web-connected kit is all about home automation, from smart lighting timers to sensors that remind you to water the plants. Joe Minihane hooks up his house

PHOTO: STUDIO4PHOTO.CO.UK

WHAT IF YOUR house could talk? What if it could tell you when the fridge is empty, when the plants need watering or even if it was being burgled? It's an idea that's long been a mainstay of science fiction, but now, thanks to a universe of internet-connected tech, it's becoming a reality.

The latest generation of gadgets, coupled with improved home broadband networks and ever cleverer phones, can make having a smart home a reality for anyone looking to secure their home, save money or simply be reminded when to go to the shops. Thanks to websites that have sprung up in the last year, these gadgets can even talk to each other, creating what's known as the 'internet of things'.

But how useful are these gadgets, really? Is a lightbulb you can switch on and off from your phone or a plant that digitally nags you to water it a massive boon, or simply a nuisance? We lived with a collection of this tech for a month to find out.

GETTING STARTED

Setting up your own 'thingernet' isn't that tough (financial clobbering aside). Products from gas controllers to Wi-Fi lightbulbs can either be plugged into your router or set up wirelessly and then controlled through your PC or, even better, your mobile. But is it actually worth the outlay and the upkeep to manage such a disparate gang of gadgets?

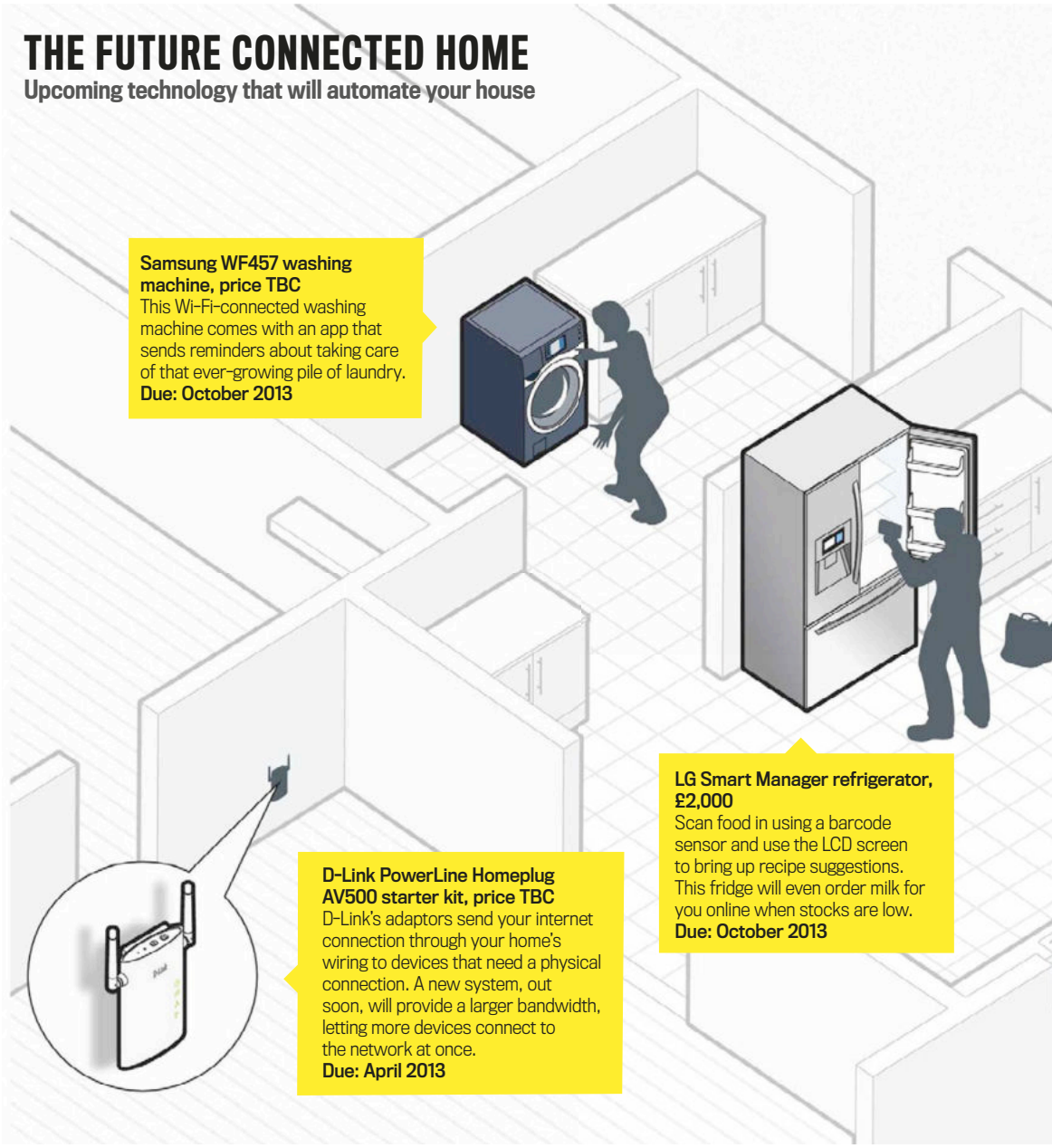
When it comes to the **Belkin WeMo Switch + Motion** (£79.95), it's a case of 'yes... and no'. The initial set-up of this Wi-Fi plug and motion detector couldn't be easier: just pop the plug into a socket, download the iOS app and follow the on-screen instructions. The excitement of being able to fire up a hairdryer using a button on the iPhone's screen is pure entertainment for roughly five minutes. Likewise, the motion detection system is a cool toy, especially when you use it with the WeMo app's 'Rules' tab to turn on electrical kit when the sensor picks up a nearby door being flung open. For instance, a radio could turn on when you enter the kitchen. Hook it up to a service called If This Then That (IFTTT), and you can create a rule that will alert you via the app if a door near the motion sensor opens, the idea being that you're wise to anyone breaking and entering.

But after a few days' play, we found it hard to see beyond the novelty factor. IFTTT rules feel fiddly, as if they're solving problems that don't exist. And it's not as if hefting ourselves off the sofa to turn on a gadget, most of which are already on standby, is really a hardship either.

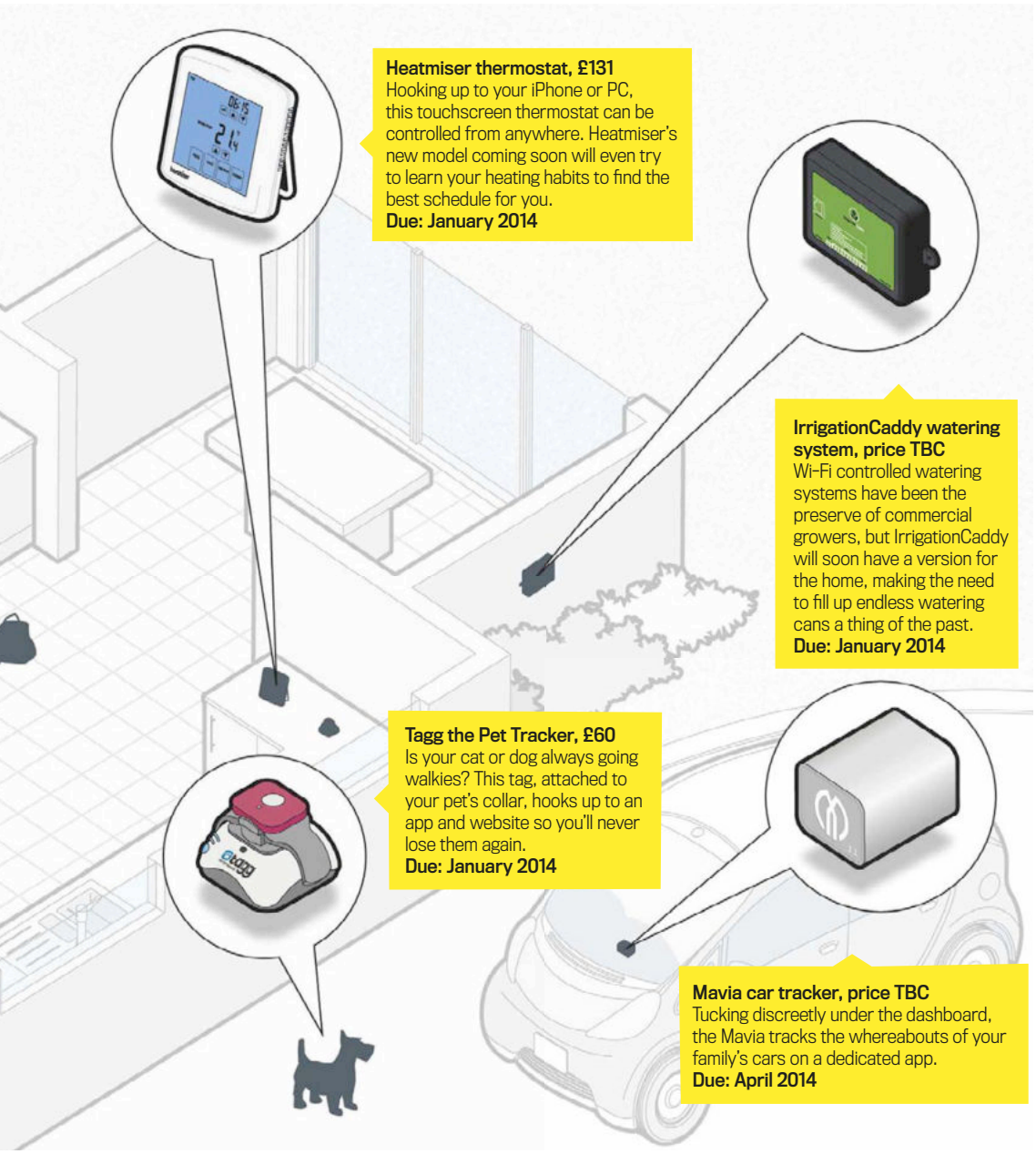
It's hard not to feel the same about **Koubachi's Wi-Fi Plant Sensor** (£100). It's a great idea: shoved into any pot before being connected to the home network, it can measure the light intensity and temperature hourly, serving up soil moisture data every five hours. Details of when to water and tend to your plant's needs are then sent to your iPhone or Koubachi's website, where you need to register first. However, while we found it a doddle to get to grips with, it quickly lost its shine. The sensor was soon forgotten as we reached for gardening magazines and Google for any plant-related queries.

A LIGHTBULB MOMENT

Far more practical is the **Philips Hue Connected Bulb Starter Pack**. At £179 for a hub and three lightbulbs, it's hardly recession-friendly, but the basic notion of being able to set lighting timers via your smartphone is very appealing. Because of the obvious security benefits – being able



ILLUSTRATOR: RICHARDPALMERGRAPHICS.COM



HOME HELP

The 'internet of things' devices that featured in our test

Belkin WeMo Switch + Motion
£79.95
www.belkin.com

Koubachi Wi-Fi Plant Sensor
£100
www.koubachi.com

Philips Hue Connected Bulb Starter Pack
£179
www.meethue.com

D-Link Wireless N Day/Night Home Network Camera
£95
www.dlink.com

British Gas MyHome Remote Heating Control
£149
www.britishgas.co.uk

to flick on lights via our iPhone wherever we were – this became a must-use product while away over Christmas. Of course, being an 'internet of things' device, it comes with a certain level of gimmickry, such as the option to choose colour shades from holiday snaps to make your house feel like a beach (apparently). But we quickly tired of this feature.

D-Link's Wireless N Day/Night Home Network Camera (£95) dispenses with novelties altogether and instead makes it clear that it's all about protecting your home. Essentially, it's a CCTV camera for the home, which you can view online or on the move on your phone. We did check back in once a day while we had it set up, only to be greeted by the same stack of unwashed mugs and scattered DVD cases every time. But if you live in a high crime area, or simply want to keep an eye on the kids, this is a savvy solution.

Perhaps the most practical of all the gadgets, though, is the **British Gas MyHome Remote Heating Control**. Though costly – with installation, it can cost as much as £229 – the idea is smart, not to mention a money-saver. Switching on your boiler while out and about is easy, and with gas prices soaring, knowing you're keeping your bill down makes this product a winner.

ROOM FOR IMPROVEMENT

When it comes down to it, having a fully connected home still feels like a slightly futuristic, awkward concept. Having to hook up myriad products to your router, sometimes via cable, can be infuriating, and take up valuable Ethernet ports. Add in the fact that you need to register to use products and websites, as in the case of D-Link, Koubachi and British Gas, and the whole process starts to feel like an exercise in jumping hurdles.

The internet of things will doubtless get better, but right now it does feel as if using more than one or two connected products is more of a hassle than a help.

JOE MINIHANE is a technology journalist

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Q&A YOUR QUESTIONS ANSWERED

BY OUR EXPERT PANEL

SUSAN BLACKMORE
Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*

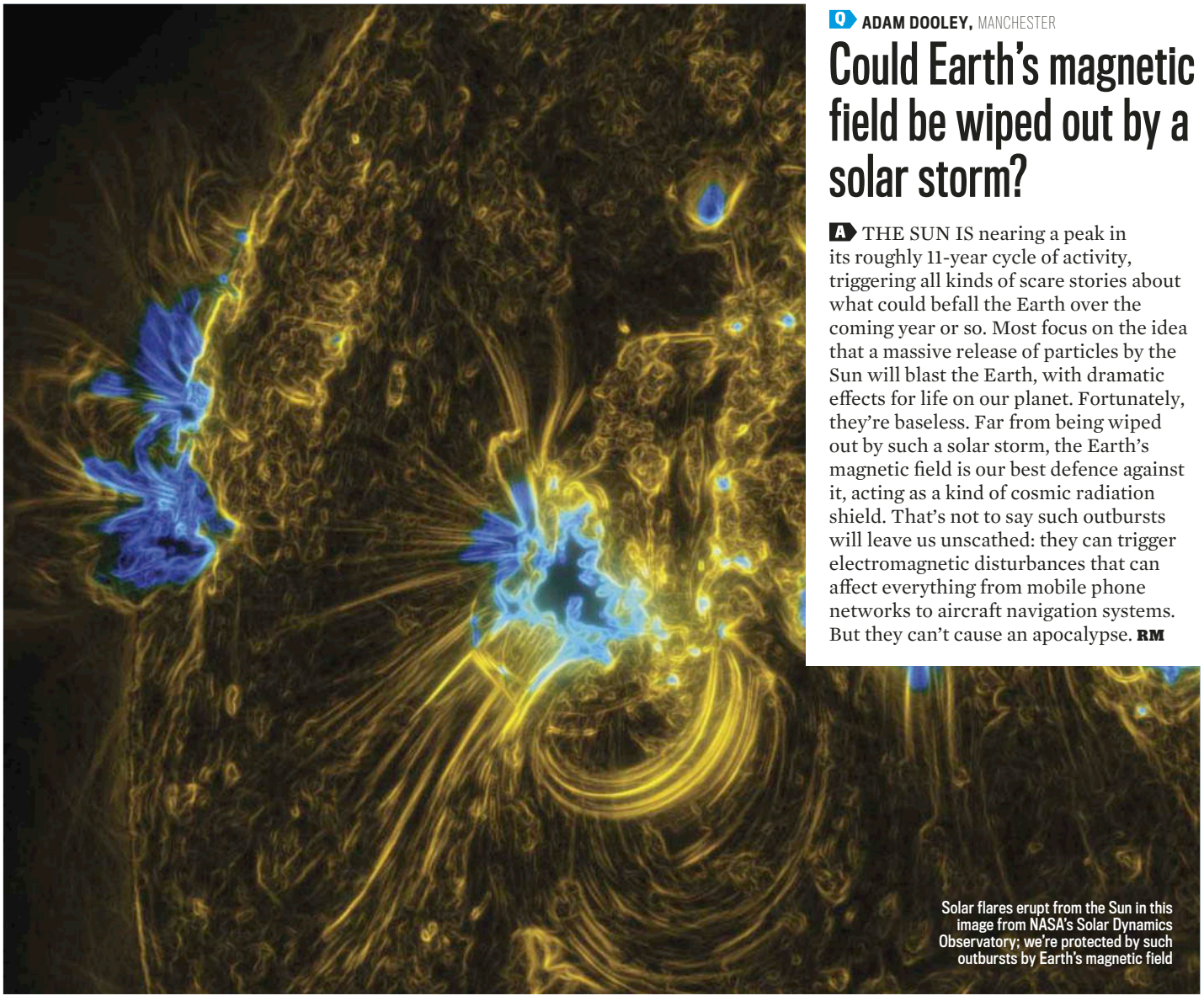
DR ALASTAIR GUNN
Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester

ROBERT MATTHEWS
After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University

GARETH MITCHELL
Starting out as a broadcast engineer, Gareth now writes and presents *Digital Planet* on the BBC World Service

LUIS VILLAZON
Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

EMAIL YOUR QUESTIONS TO questions@sciencefocus.com
or post to *Focus* Q&A, Tower House, Fairfax Street, Bristol, BS1 3BN



Solar flares erupt from the Sun in this image from NASA's Solar Dynamics Observatory; we're protected by such outbursts by Earth's magnetic field

PHOTO: NASA/SDO

Q **ADAM DOOLEY,** MANCHESTER

Could Earth's magnetic field be wiped out by a solar storm?

A THE SUN IS nearing a peak in its roughly 11-year cycle of activity, triggering all kinds of scare stories about what could befall the Earth over the coming year or so. Most focus on the idea that a massive release of particles by the Sun will blast the Earth, with dramatic effects for life on our planet. Fortunately, they're baseless. Far from being wiped out by such a solar storm, the Earth's magnetic field is our best defence against it, acting as a kind of cosmic radiation shield. That's not to say such outbursts will leave us unscathed: they can trigger electromagnetic disturbances that can affect everything from mobile phone networks to aircraft navigation systems. But they can't cause an apocalypse. **RM**

Q **SOPHIE FOOTITT,** FRANCE

What is snot?

A THE INSIDE OF your nasal passages are lined with mucous membranes. These contain goblet cells which secrete proteins that dissolve in water to form mucus. The water comes from the vapour in your breath and it's also squeezed out of the blood through the tiny gaps in the walls of the capillaries that line the nose. When you are healthy, the microscopic hair-like cilia cells in the nose keep the mucus flowing to the back of your throat, where it is swallowed. This removes dust and airborne bacteria where they can be disposed of by your stomach acid. If you have an infection, the viruses can manipulate this mechanism to increase the amount of mucus produced. This overwhelms the cilia and a mixture of mucus, dead white blood cells, and virus particles leaks out. This unpleasant cocktail is called snot and it's one way used by viruses to spread from person to person. **LV**

Hair-like cilia waft mucus to the throat, but they can't handle an excess of it

In Numbers

17 billion

The estimated number of planets in our Galaxy that are a similar size to Earth, taken from NASA's Kepler mission data

Q **JOSEPH TING,** BRISBANE, AUSTRALIA

Can crows recognise human faces?

A AMAZINGLY, THEY CAN. Many birds recognise individual humans but they probably do this by using a variety of cues, including height, build, colour, clothes or ways of walking. Crows, however, can actually recognise faces. This has been confirmed by experiments in which scientists put on various masks and then trapped a group of wild crows and fixed rings to their legs. After letting the birds go, they walked around recording whom the crows mobbed or scolded with their harsh, warning cries. The trapped crows, which had previously ignored these individuals, now reacted aggressively to anyone wearing the trappers' masks, regardless of their size, clothes, or gait. **SB**

There's a lot more going on behind the beak than you might think

Q **JOHN DRAKE,** ST ALBANS

What are the chances a headache pill will work?

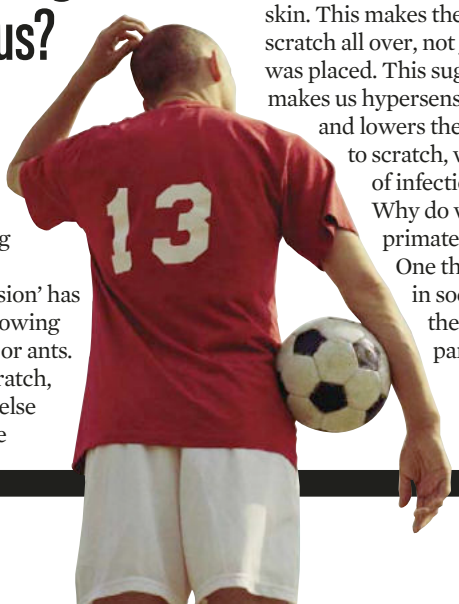
A WHEN TAKING A painkiller, it's hard to avoid thinking that the pain may well have cured itself by the time the drug takes effect. And this might be true: studies of the best over-the-counter painkillers like paracetamol show that fewer than one in three people who take them will actually benefit. **RM**

A headache may well have lapsed before a painkiller works

Q **MARK PURCELL,** IRELAND

Why can itching be contagious?

A LIKE YAWNING AND coughing, scratching can be infectious. You see someone else scratching and soon you feel itchy yourself. 'Itch transmission' has been investigated by showing people pictures of fleas or ants. This can make them scratch, but watching someone else scratching produces the strongest response. A possible clue as to why this happens may be revealed when a drop of histamine is dropped on someone's skin. This makes them itchy, but they scratch all over, not just where the drop was placed. This suggests a mechanism that makes us hypersensitive to skin sensations and lowers the threshold for wanting to scratch, which may be the cause of infectious scratching. Why do we have it? Other primates behave this way too. One theory is that it evolved in social species to help them notice and deal with parasitic infestations. **SB**

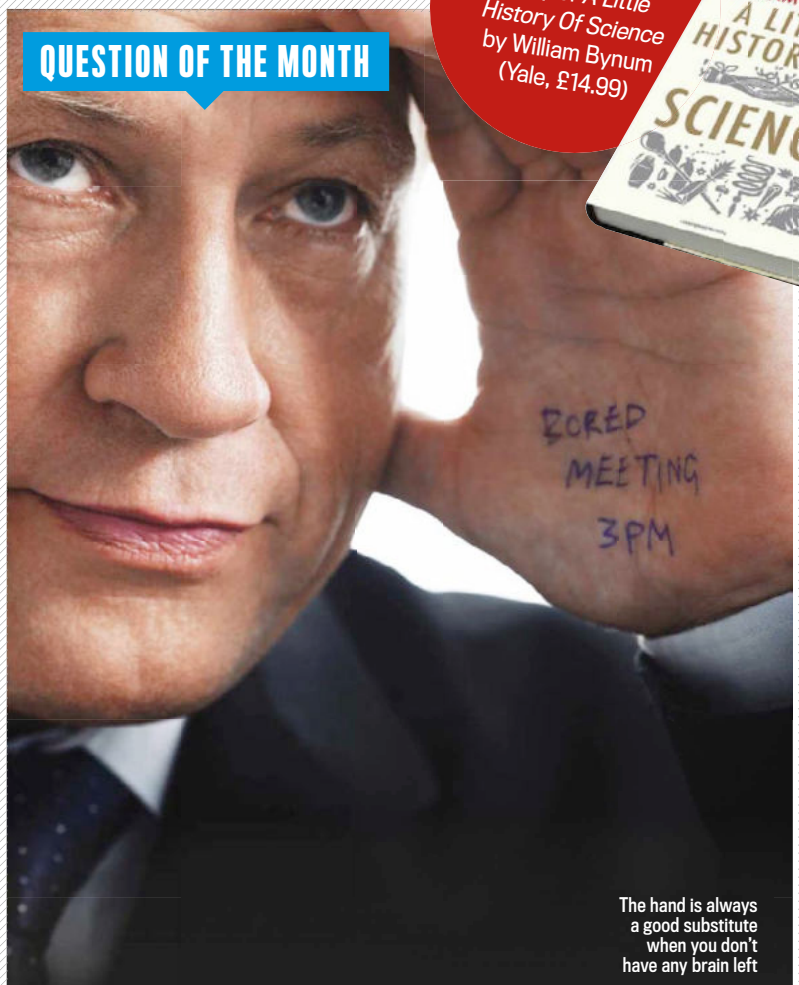


Are you feeling itchy? Go on, you know you want to...

PHOTO: SCIENCE PHOTO LIBRARY, GETTY X2, THINKSTOCK, ALAMY X2

QUESTION OF THE MONTH

WINNER! George wins a copy of *A Little History Of Science* by William Bynum (Yale, £14.99)



The hand is always a good substitute when you don't have any brain left

Q **GEORGE MCKENZIE,** BY EMAIL

Could the human mind ever run out of memory?

A IN ONE SENSE, yes. Memory depends on forming new neural connections, and the brain has a finite number of neurones and a limited space in which to add more connections between them. Yet in another sense a healthy brain can never stop learning.

There is really no such thing as 'a memory'. When we remember a fact or an event that happened to us, many networks of interconnected cells are involved. Sometimes, if we can't remember an event one way, we can bring it to mind another way using different connections. As we age, and have more and more to remember, the connections get more complex. When our brains are overloaded the same neurones are used in multiple memories in very flexible ways. So we might become more likely to confuse events, or have other difficulties in remembering, but we can't really say that we 'run out of memory'. **SB**

The arrival of spring means better weather but more nose-withering pollen too

Q **SARAH SYKES,** LUTTERWORTH

What time of year is worst for allergies?

A SEASONAL ALLERGIES ARE caused by airborne pollen. These tiny particles have lots of surface proteins that can trigger an excessive immune response, which leads to a runny nose, itchy eyes and sneezing. In spring, tree pollen levels peak in the second week of May. Then there is a second peak in September from grass pollen. **LV**

Q **BEN RIDDLE,** LEEDS

Why doesn't software open instantly?

A THE MAIN FACTOR is the time taken to load applications from the hard drive into the computer's memory. Flash memory speeds things up, but you can also use the computer's RAM as a virtual hard drive. To the operating system, the RAM drive behaves like a traditional hard disk. But with no moving parts, applications launch from this virtual drive almost instantaneously. **GM**

Q **DYLAN RITCHIE,** LIVINGSTON

Why do voices sound higher when sped up?

A TAKE WHAT HAPPENS when you record a musical note. Middle C has a frequency of 262Hz. If you double the playback speed, the peaks and troughs on the note's waveform cycle twice as fast. The frequency thus doubles to 524Hz, an octave higher. Our voices are made up of a mix of frequencies, so as they are sped up, then like the musical note, they rise in pitch. **GM**

TOP TEN
TALLEST BUILDINGS

1. Burj Khalifa
Dubai, UAE
828m
163 floors

2. Abraj Al-Bait Towers
Mecca, Saudi Arabia
601m
120 floors

3. Taipei 101
Taipei, Taiwan
509m
101 floors

4. Shanghai World Financial Center
Shanghai, China
492m
101 floors

5. International Commerce Centre
Kowloon, Hong Kong
484m
118 floors

6. Petronas Towers
Kuala Lumpur, Malaysia
452m
88 floors

7. Zifeng Tower
Nanjing, China
450m
89 floors

8. Willis Tower
Chicago, USA
442m
108 floors

8. Kingkey 100
Shenzhen, China
442m
100 floors

10. Guangzhou West Tower
Guangzhou, China
440m
103 floors

Got a cold? Then you have the excuse to over-eat

Q **JAMES KIRKE,** WALSALL

Is there any truth in 'starve a fever, feed a cold'?

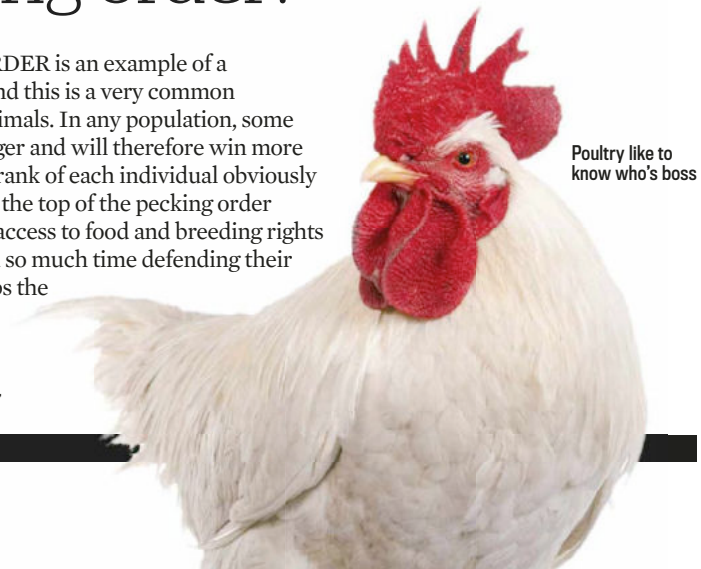
A THIS ADVICE HAS been around since 1574, when dictionary writer John Withals wrote that 'fasting is a great remedie of feuer [fever]'. It was thought that fever was a symptom of an overactive metabolism and eating would exacerbate this, while colds were caused by the body getting too cold. Both are false.

However, a study in 2002 at Amsterdam Academic Medical Centre found that fasting boosts the immune response that tackles bacterial infections (which commonly cause fever), whereas eating encourages killer T cells that attack cells infected with a virus, such as the cold virus. **LV**

Q **MAX WILLOWS,** OXFORD

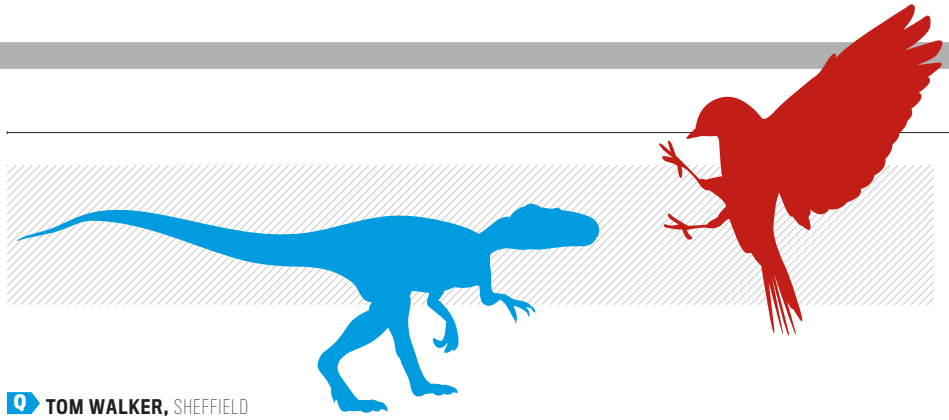
Why do chickens have a pecking order?

A THE PECKING ORDER is an example of a dominance hierarchy and this is a very common behaviour pattern in animals. In any population, some will be stronger and larger and will therefore win more fights. Establishing the rank of each individual obviously benefits the chickens at the top of the pecking order because they have first access to food and breeding rights and don't need to spend so much time defending their position. But it also helps the weaker ones because they reduce their chance of injury in fights they can't win. **LV**



Poultry like to know who's boss

PHOTO: ALAMY X2, THINKSTOCK X2



Q **TOM WALKER,** SHEFFIELD

How did cold-blooded dinosaurs become warm-blooded birds?

A MAYBE THEY DIDN'T! One possibility is that dinosaurs, although they resemble today's cold-blooded reptiles, actually maintained a steady body temperature just as mammals do. Evidence from fossil bones suggests a rate of growth compatible with endothermic metabolism – that is, producing heat from within to maintain body temperature. Also many dinosaurs lived in cold environments where getting enough heat from the surroundings might have been too difficult for cold-blooded animals to survive.

Finally, some of the largest dinosaurs, such as Brachiosaurus, had such long necks that they would have needed endothermic metabolism to fuel their blood circulation. If this is true, there is no mystery about warm-blooded birds; they are descended from warm-blooded dinosaurs. **SB**

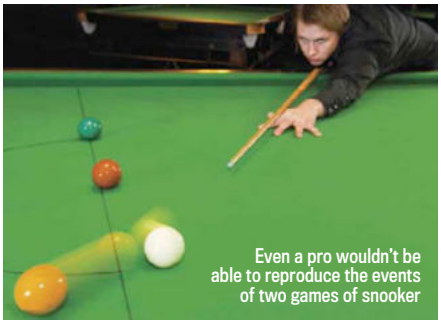
WHAT IS THIS?

KNOW THE ANSWER?
Go to **sciencefocus.com/qanda/what** and submit your answer now!

LAST MONTH'S ANSWER:
Well done to Eva Engelbrecht, who correctly guessed a baby Pudu deer.

Q **LEN ROGERS,** LONDON

What are the chances of having two identical snooker games?



Even a pro wouldn't be able to reproduce the events of two games of snooker

A VERY SLIM INDEED, because snooker involves so-called chaotic processes, in which just small changes produce radically different outcomes. Rough calculations shows that if two snooker games are played with the first red ball struck to within a hair's breadth of the exact same position, the games will be hugely different after around half a dozen shots. **RM**

Did you know?
The largest fish is the Whale Shark, with one specimen reaching 12.6m in length.

Q **CLARE MATTHEWS,** CANTERBURY

Does your blood group influence your personality?

A IN JAPAN AND South Korea this is a popular notion, with type A thought to be anxious perfectionists and good team players, type O curious, generous and stubborn, AB arty and unpredictable, and type Bs cheerful, eccentric and selfish. There's no biological reason for this – your blood type is just a question of which surface proteins are attached to your red blood cells – and there is no research to support the idea.

Rather like your astrological star sign, it's possible that knowing what personality type you are 'supposed' to have might cause you to exaggerate or attach extra significance to the occasions when you behave true to type.

This is an example of confirmation bias, where we pay more attention to evidence that appears to support our prejudices than to evidence that contradicts them. Most of us behave with a mixture of all the blood-type personality traits. **LV**

If your blood is type AB, you should be arty and unpredictable; and gullible if you believe that

Q **DUNCAN BURGESS,** SHETLAND

How many planets will be engulfed when the Sun dies?

A IN 5 BILLION years, the Sun will expand to become a 'red giant'. It will engulf the planets Mercury and Venus, but the Earth's fate is less clear. As the Sun swells up to 250 times its present size, it will lose more than a third of its mass in a strong 'stellar wind'. This will cause the planets' orbits to widen significantly so that the Earth may just escape the out-rushing Sun. However, the Earth's gravity could tug the Sun's surface just enough to create a tidal effect and pull the Earth back in to a closer orbit. Even so, our planet will have been long dead; 3 billion years from now the Sun's energy output will have evaporated the oceans. **AG**

Earth will be roasted by the Sun in 5 billion years' time

Q **MOHAMMAD RASHID,** WAKEFIELD

Why do we make the 'atchoo' sound when we sneeze?

A A SNEEZE BEGINS with a sudden inhalation. This is the 'Aaah' part of the sneeze. The 'Choo!' occurs on the exhale because most of the muscles in your body are reflexively contracting. This clamps your mouth shut until the pressure in your lungs rises too high and the air escapes in a burst. Since your tongue is pressing against the roof of your mouth, the air makes a 'ch' sound, and with your lips pursed, it emerges as an 'oo'. **LV**

Never mind how the sound is made, get away from it!

Did you know?

The largest cave in the world is Vietnam's Hang Son Doong (Mountain River Cave). It's 200m high, 150m wide and 6.5km long.

Q **BARBARA BASS,** FACEBOOK

Can solar panels be damaged by solar flares?

A SOLAR FLARES OCCUR when regions on the Sun's surface brighten dramatically. That intensifies the sunlight, but by a negligible amount and certainly nowhere near enough to overload solar panels here on Earth.

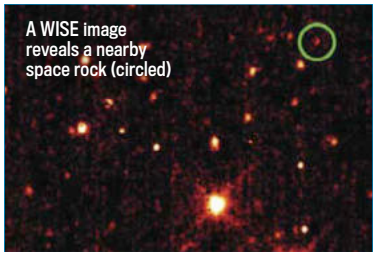
However, solar flares can be accompanied by coronal mass ejections (CMEs). These intense magnetic pulses course through the Solar System and, if aimed at the Earth, interact strongly with our magnetosphere. The resulting fluctuating magnetic fields induce currents in electrical conductors, so CMEs can affect electricity supply grids and even radio communications, especially at the poles. Could they also affect the photovoltaic semiconductors at the heart of solar panels? Theoretically a strong enough magnetic field could induce a current capable of frazzling the electronics around it. But individual solar cells are too small for sufficiently damaging currents to be induced. Magnetic avalanches from the Sun are only able to disrupt electricity grids because power lines stretch across hundreds of kilometres. **GM**

The small size of photovoltaic cells means that a coronal mass ejection would struggle to fry them

Q **NORMAN FAULKES,** HONITON

NASA's found 94 per cent of near-Earth asteroids; how does it know how many it's missed?

A IF YOU KNOW how well a telescope can detect a type of object, it's possible to estimate how many objects would have been discovered if a survey had been complete. In this particular case, scientists made an imaginary 'population' of near-Earth asteroids (NEAs) over 1km wide and studied how their WISE telescope performed in detecting them in a computer model. Comparison with actual survey results revealed an estimate of how many NEAs they missed. **AG**

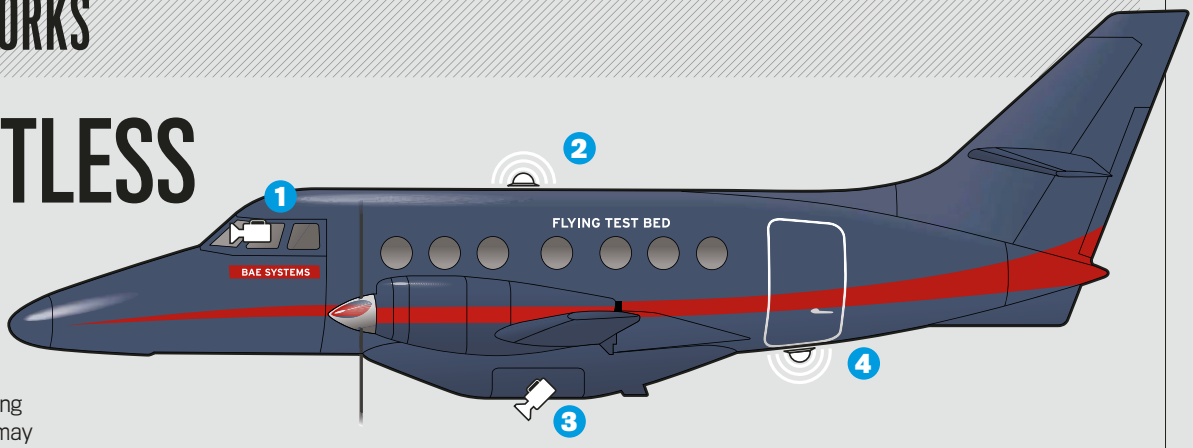


A WISE image reveals a nearby space rock (circled)

PHOTO: SCIENCE PHOTO LIBRARY, ROBERT HARDING, NASA, THINKSTOCK ILLUSTRATOR: ANDREW BAKER

HOW IT WORKS

THE PILOTLESS PLANE



WITH ALL THE hype surrounding Google's driverless cars, you may not have heard of something even more remarkable: the pilotless plane. Technology being developed by BAE Systems could mean that one day it won't matter if your pilot nods off during a flight.

The system needed to do this has been put through its paces over the Irish Sea. Integrated into a small passenger plane called (somewhat uninspiringly) 'The Flying Testbed', the technology, together with satellite communications, can do far more than your typical autopilot. While an autopilot can keep a plane on a level, accurate flight path and perform a landing, the new system is able to think for itself. The technology could be used in an emergency situation when the crew have been rendered unconscious, for instance. However, there are currently no plans to commercialise the system.

Using a camera mounted in the cockpit and a bank of computers in the tail, the aircraft can detect different cloud types before plotting evasive action if necessary – a world first. Similarly, the 'brain' of the plane has 'sense and avoid' technology, using its Aircraft Identification Antenna to pick up aircraft transponder signals. If it doesn't pick up a signal, the camera is used to make visual contact before the computer plots a safe course.

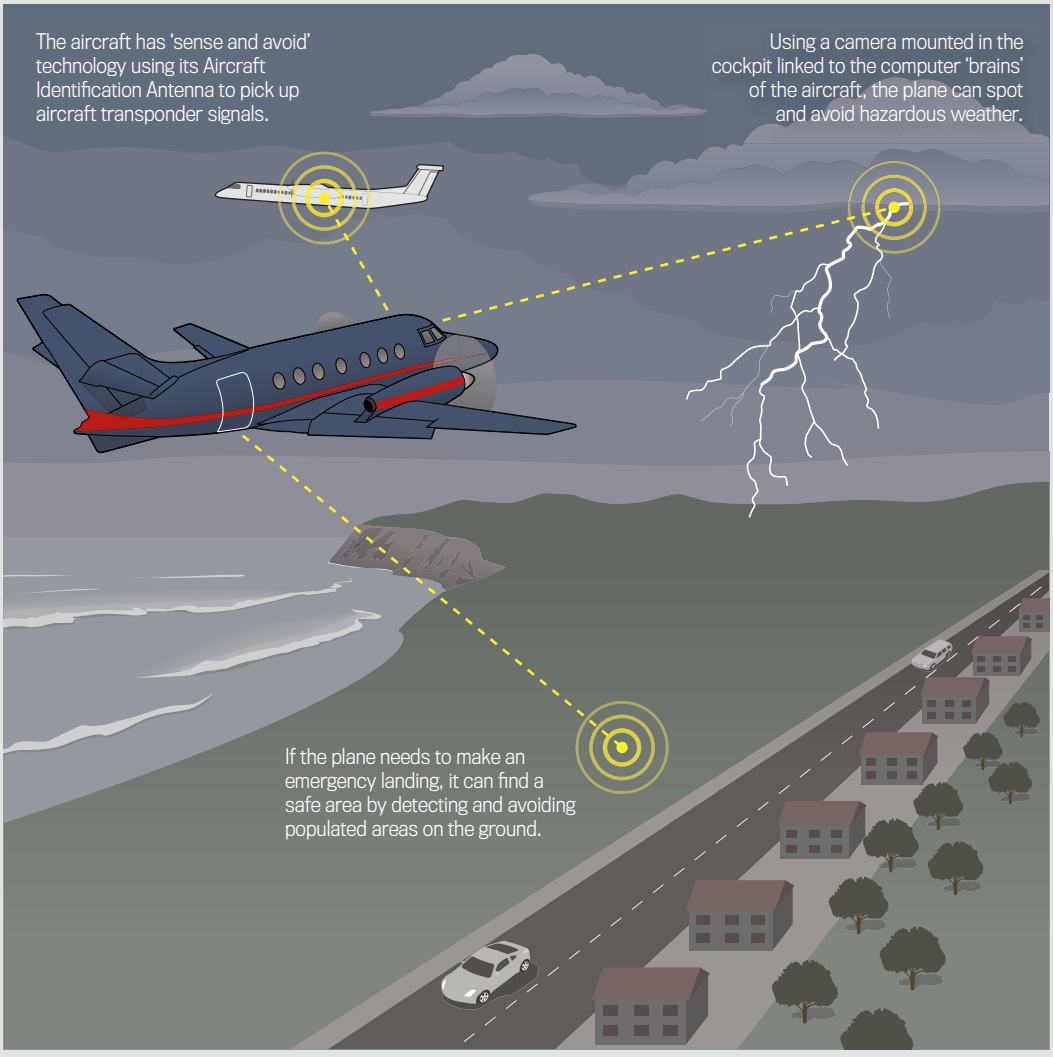
Finally, if you were to find yourself in the brace position, you're in safe hands. The aircraft is able to use an infrared camera mounted underneath, as well as its antenna, to detect a suitable landing site.

1 A cockpit-mounted camera detects potentially dangerous weather and nearby aircraft.

2 The plane uses an antenna on the top for ground-based and satellite communications.

3 An infrared camera can detect a suitable location to make an emergency landing.

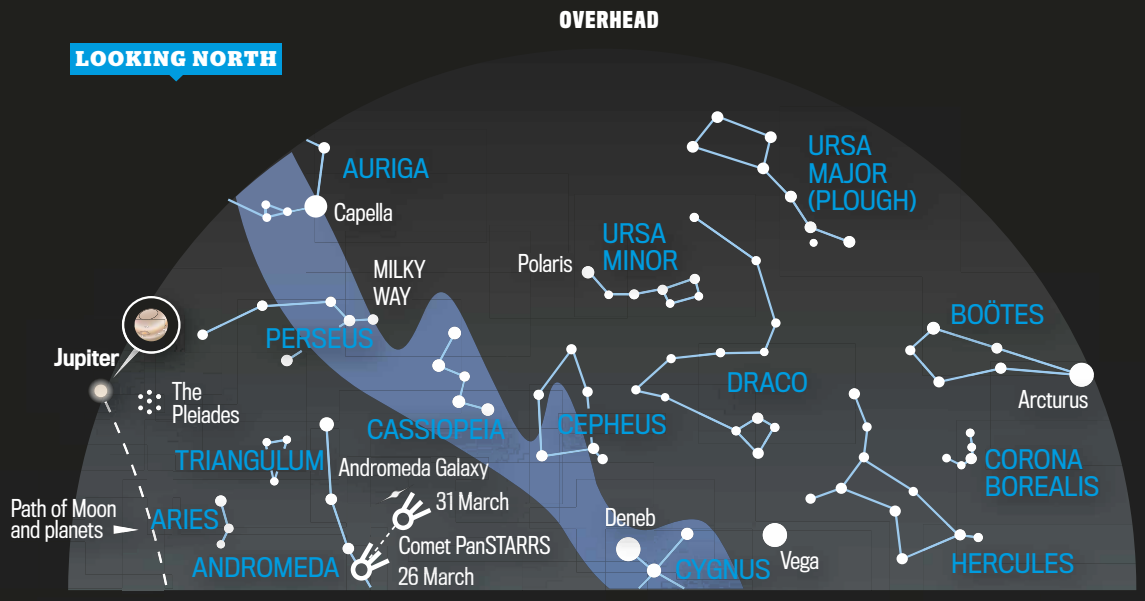
4 The Aircraft Identification Antenna enables the plane to avoid nearby aircraft.

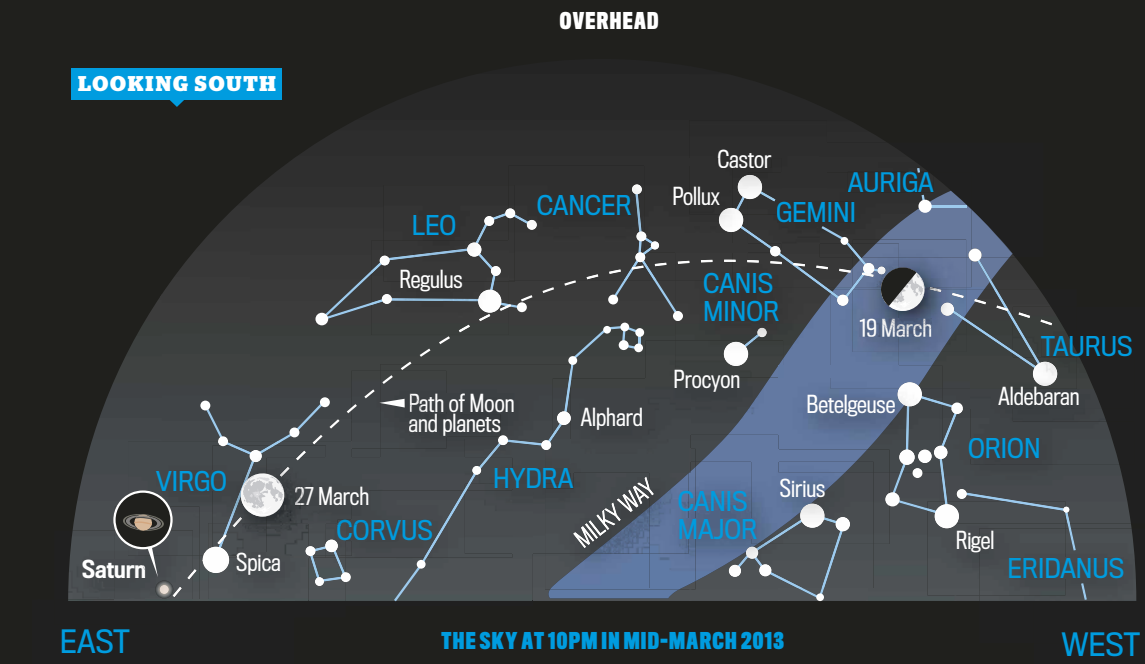


THE NIGHT SKY: WHAT CAN I SEE IN MARCH?

Astronomy with Heather Couper and Nigel Henbest

THE SKY IS changing as spring beckons. The dazzling winter constellations, like Orion, are shifting to the west, giving way to the more subtle constellations of Leo and Virgo. There are two bright planets to whet the appetite: dazzling Jupiter is joined now by fellow gas giant Saturn; and possibly the rare sight of a naked-eye comet. And don't forget that you'll lose an hour's sleep on 31 March, when the clocks go forward to herald British Summer Time!





LOOKING NORTH

17/18 March, evening
The crescent Moon gets close to the giant planet Jupiter and the Pleiades star cluster, with the Hyades cluster to the left. Great to look at with the unaided eye – but a magical sight through binoculars.

15–31 March, after sunset
Look low to the northwest to search out Comet PanSTARRS, named after the sky-survey telescope in Hawaii that found it. The chart shows its track, but its brightness is almost impossible to predict: binoculars should reveal PanSTARRS, and there's a chance it could be visible to the naked eye.

LOOKING SOUTH

All month, 10pm onwards
Saturn makes a welcome return to our skies. It's a 'must' through a telescope, which will show its rings and its largest moon, Titan. Titan has seas – and even running rivers – of ethane and methane.

All month, evening
Regulus marks the 'heart' of Leo, the Lion – a constellation that clearly resembles a giant sprawling feline. Bright Regulus is a young star that rotates in less than 16 hours, almost fast enough to tear itself apart.

All month, evening
The straggly constellation of Hydra is the biggest in the sky. It's made up of faint stars, apart from the medium-bright Alphard – aptly named 'the solitary one'. See if you can spot the star blazing away in a relatively sparse patch of sky.

Find out more

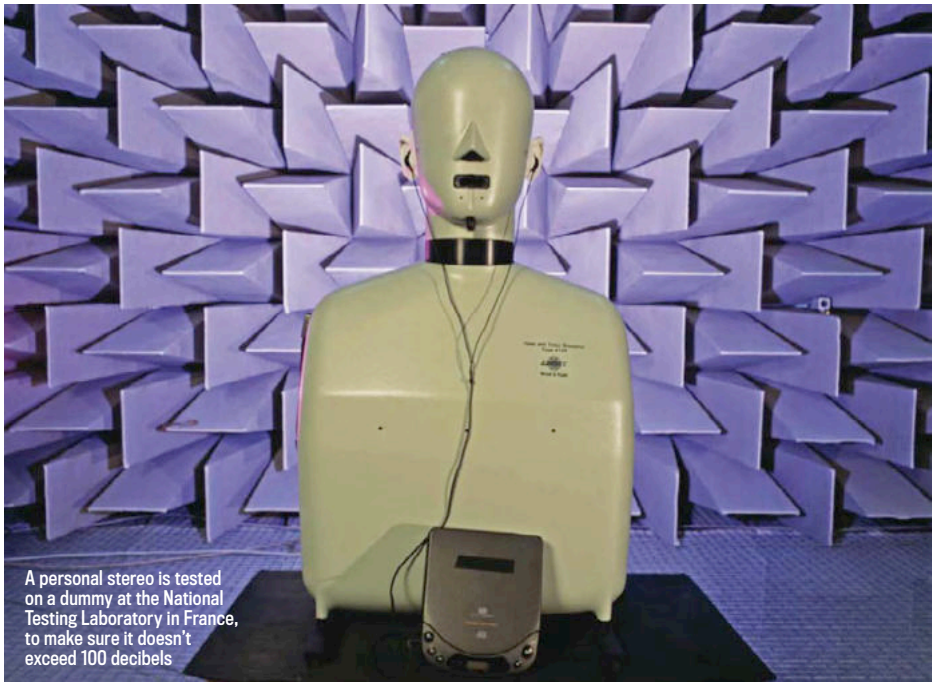
Stargazing 2013
Discover astronomy with Heather Couper and Nigel Henbest (Philip's, £6.99)

The *Quetzlcoatlus* had the same wingspan as an F16 jet

Q **EVA SMITH,** EXETER

How did the biggest dinosaurs fly?

A WITH GREAT DIFFICULTY. The largest pterosaurs (which aren't actually classified as dinosaurs) were much bigger than even the largest flightless birds alive today. *Quetzlcoatlus*, for example, was the size of a giraffe. The highest estimates of its weight are 200–250kg, and at that weight there is no plausible mechanism for *Quetzlcoatlus* to get airborne. Part of the problem is that all the *Quetzlcoatlus* fossils are found far inland, away from sea cliffs or mountains that might provide a launch platform. But for body weights of 70–80kg, a simulation at Texas Tech University showed that the beast may have used slopes at the edges of lakes as runways. It would begin by running on all fours with its huge wings folded. It would then shift onto its back legs and begin flapping. Finally, it lunged forward and lifted its back legs off the ground. Once aloft, *Quetzlcoatlus* was capable of efficient, soaring flight. **LV**



A personal stereo is tested on a dummy at the National Testing Laboratory in France, to make sure it doesn't exceed 100 decibels

Q **LUKASZ MUSIALOWICZ,** LONDON

Are earphones really damaging to health?

A DOCTORS HAVE LONG warned of the damaging effects of prolonged exposure to loud music via earphones. The popularity of portable cassette players in the 1980s led to studies claiming that around 1 in 20 people were risking Noise-Induced Hearing Loss.

Yet while there is no doubt that exposure to loud noise from, for example, machinery can lead to permanent damage, evidence that music from portable devices does the same has remained elusive. That's changing, however, as scientists focus on finding actual physical damage to nerves. Dr Martine Hamann and colleagues at the University of Leicester recently published the first evidence of such harm, by showing that loud noises strip nerve cells of their protective coating, preventing them from reliably transmitting signals from the ear to the brain.

This confirms previous studies showing that even brief exposure to loud music can reduce the sensitivity of the ear. But the finding also explains why evidence of permanent damage has been elusive. Dr Hamann found that nerve cells repair themselves, replacing the outer layer after a few months – if they're given the chance. **RM**

Did you know?

The Boeing Everett factory, Washington state, is the world's largest. It covers 399,483m² and is used to build passenger aircraft.

Q **JOSEPH VENABLES,** WEST CHESHIRE

At what point of the day do children grow the most?

A GROWTH IS CONTROLLED by the hormones somatotropin and insulin-like growth factor 1 (IGF-1). Levels of these hormones are highest in children and adolescents while they are sleeping. But you can't necessarily conclude from this that children grow fastest at night. For one thing, no correlation between the amount of sleep children get and their height has been proved. For another, even a newborn only grows 25cm in its first year. That's just 0.68mm per day and trying to measure this accurately enough to graph the growth rates at different hours of the day is almost impossible. **LV**

Maybe it would be better to measure children at night?

NEXT MONTH Over 20 more of your questions answered

For even more answers to the most puzzling questions, see the Q&A archive at **www.sciencefocus.com/qanda**

PHOTO: SHUTTERSTOCK, CORBIS, SCIENCE PHOTO LIBRARY

HOW DO WE KNOW?

THE EXPANSION OF THE UNIVERSE

BY ALEXANDER HELLEMANS

In less than a decade, astronomers replaced the view of a static Universe with one driven apart by a huge explosion, the Big Bang. How did this happen?

JUST AS IN cinema, the arts and design, the 1920s were magical years for science. It was the time when quantum theory and nuclear physics revolutionised our understanding of matter. It was also the time when Einstein showed that the Universe had to contract or expand. And it was a time when new and powerful telescopes became available, allowing astronomers to explain the nature of the many mysterious fuzzy patches in the sky, such as the Andromeda Nebula. Our understanding of the Universe underwent a true revolution: instead of a single and static Milky Way system we had a Universe filled with billions of galaxies. It had started with a huge explosion – the Big Bang – and expanded in all directions.

Since prehistoric times, civilisations in all parts of the world had tried to explain the structure of the Universe. Many ancient world views, such as that of the Mesopotamians, were quite detailed, being based on religious myths and linked to the immediate experience of the world.

The Ancient Greeks introduced a 'scientific' cosmology by the use of geometric concepts such as rotating spheres. For Aristotle, the Earth was the centre of the Universe, and the Sun, planets and stars rotated around the Earth on different spheres. Adopted by the Roman Catholic Church, this model survived in the Christian world until the Renaissance.

THE MERCURY PROBLEM

In 1610, when Italian scientist Galileo Galilei pointed his telescope to the heavens, the view of the Universe changed drastically. He discovered the phases of Venus and realised that Venus reflected light from the Sun. Galileo now had proof that the planets orbited the Sun, an idea first suggested by Nicolaus Copernicus in 1543, and that brought him into conflict with the Church authorities in Rome.

Observing that the Milky Way consisted of a large number of stars, Galileo realised that the Sun and planets were merely a small part of the Universe – the Milky Way.

Isaac Newton had the same idea, but said that the Universe is infinite and static – it is not changing and will last forever. This view of the Universe remained essentially unchanged until the beginning of the 20th century. After Newton, many scientists perfected his theory of gravity, which allowed the prediction of the passage of comets and the calculation of planetary orbits with very high precision. However, there was a snag: no matter how much astronomers tried, they could not explain why the elliptical orbit of Mercury rotated faster than calculations predicted.

In 1915 Einstein developed a new theory of gravitation, General Relativity, in which the curvature of space-time is caused by the presence of mass, and objects in space move along this curvature. Einstein's theory explained why the orbit of Mercury rotated faster than predicted by Newton's equations. But he encountered a difficulty with the theory of General Relativity when he applied his equations to the Universe: he found that it should

PHOTO: SCIENCE PHOTO LIBRARY

> IN A NUTSHELL

Our understanding of the Universe has come a long way since the days of Aristotle and Ptolemy. But until as recently as the early 20th century, astronomers believed our Galaxy, the Milky Way, was all there was. Today, we know that there are untold billions of galaxies – and that they're moving apart at ever-increasing speeds.

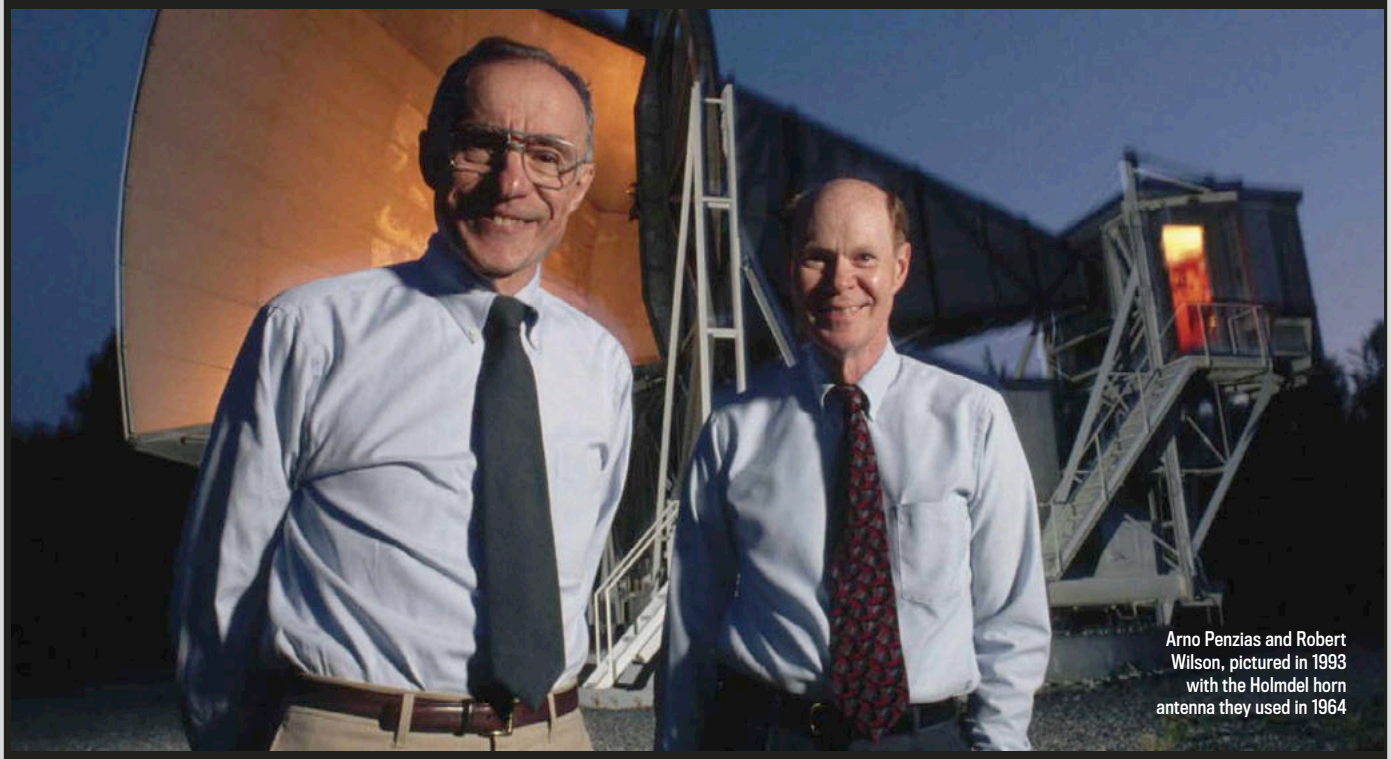
either contract or expand. Like most astronomers at the time, he believed that the Universe should be static. So in 1917 he introduced the 'cosmological constant', a parameter that would counteract gravitational forces which would otherwise cause the Universe to expand or contract. Einstein later came to realise that he should have had more trust in his own theory – the cosmological constant would prove to be his biggest mistake.

The German philosopher Immanuel Kant, upon learning about the observation of spiral nebulae in 1750 by the English astronomer Thomas Wright, proposed in 1755 that they might be "island universes" just like the Milky Way. Kant's idea met with little acceptance and most astronomers viewed spiral nebulae as part of the Milky Way – possibly solar systems in the making. So did the astronomer Percival Lowell, the founder of Lowell Observatory, who in 1901 hired Vesto Melvin Slipher. Slipher had a degree in astronomy and mechanical engineering, a combination that soon proved fortuitous. Having mastered the observatory's spectroscope, a 200kg precision instrument attached to the 24-inch telescope of the observatory, he recorded numerous spectra of planets and stars. These spectra allowed atoms to be identified in the atmospheres of planets.

Lowell, who hoped to identify planets in the Andromeda Nebula, asked Slipher to record spectra of the nebula. Slipher, with his technical acumen, improved the sensitivity of the spectroscope and obtained a detailed spectrum of the Andromeda Nebula in 1912. But to their surprise they found that the spectral lines were

THE KEY EXPERIMENT

The discovery of cosmic microwave background radiation in 1964 offered proof that the Big Bang really had occurred, laying Hoyle's rival Solid State theory to rest



Arno Penzias and Robert Wilson, pictured in 1993 with the Holmdel horn antenna they used in 1964

In 1964, two physicists working at Bell Labs in Holmdel, New Jersey, Arno Penzias and Robert Wilson, experimented with a very sensitive microwave horn antenna. Originally designed to bounce radio signals off Earth-orbiting balloons, it was retired because the ECHO communication system was discontinued. The two physicists geared up the 6m antenna to search for radio waves emitted in the spaces between galaxies and fitted it with a receiver that was cooled to 3°C above absolute zero to eliminate any radio noise coming from its own components. They detected a strange 'radio interference' that remained constant in all directions. Thinking that the noise might originate in the antenna itself, they even cleaned out the pigeon droppings.

Becoming convinced that this radiation had to come from the Universe, they contacted Robert Dicke, a theoretical physicist at Princeton University, who had predicted that the Big Bang would have left behind a remnant of radiation corresponding to 3°C above absolute zero, the temperature to which the Universe had cooled down. The discovery of this 'cosmic background radiation' confirmed the existence of the Big Bang, putting to rest Hoyle's Steady State theory. For their discovery, Penzias and Wilson received the Nobel Prize for Physics in 1978.

PHOTO: SCIENCE PHOTO LIBRARY X3, CORBIS X2, GETTY

shifted by a large amount to the blue, showing that the nebula approached us with a velocity of 300km per second. This was faster than the speed of any known object in the Milky Way.

When in 1914, Slipher presented spectroscopic determinations of the speed of 15 nebulae at a meeting of the American Astronomical Union, he received a standing ovation. His colleagues, however, remained perplexed by the data presented. The spectra of the majority of the galaxies were redshifted, and the redshift of one of them corresponded to a motion away from us at 1,000km/s.

The nature of these nebulae had become more of an enigma than ever. But new observations with improved telescopes slowly began to lift the veil.

MEASURING UP

One of the problems in astronomy was that there was no way to determine the distance of faraway stars or other celestial objects. For example, a very distant, massive and hot star can shine with the same apparent brightness as a star that is close, small and cool.

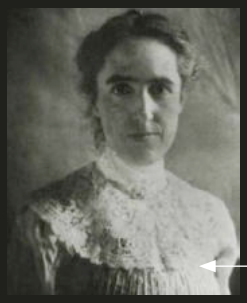
In 1912, the astronomer Henrietta Swan Leavitt made a discovery that became crucial to our understanding the Universe: she found a type of star that tells you how far away it is. Leavitt belonged to a team of women appointed by the astronomer Edward Charles Pickering who determined the apparent brightness of stars on photographic plates. Leavitt focused on a group of variable stars, called Cepheids, that change their apparent brightness with a periodicity ranging from a day to several months.

She measured these changes in a group of Cepheids that were located in the Small Magellanic Cloud. Certain that these Cepheids were all at the same distance from Earth, she made a surprising discovery: the period of variations in brightness of these Cepheids was related to their intrinsic brightness. By comparing the intrinsic brightness of the Cepheids to their apparent brightness, she found that the Small Magellanic Cloud had to be outside, but near, the Milky Way.

In 1917 Heber D Curtis, an astronomer investigating nebulae at Lick Observatory on Mount Hamilton in California, observed a nova in the Andromeda Nebula. The nova – an exploding star – was so bright that it outshone the entire nebula.

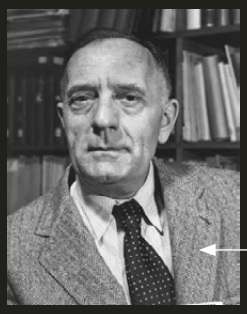
CAST OF CHARACTERS

The astronomers who shaped our modern understanding of the Universe



Henrietta Swan Leavitt (1868–1921) American astronomer who discovered the relation between the intrinsic luminosity and period of Cepheid variable stars. This relation enabled Edwin Hubble to gauge the distance of galaxies.

Vesto Slipher (1875–1969) Slipher, an American, perfected spectroscopy and determined the redshift of a number of galaxies, allowing their recession velocities to be determined.



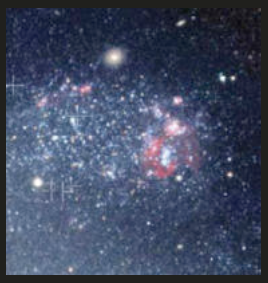
Edwin Powell Hubble (1898–1953) Hubble determined the distance of a number of nebulae and found that the more distant the galaxy, the faster it is moving away from Earth, showing that the Universe is expanding.

Georges Lemaître (1894–1966) A Belgian priest and astronomer who developed an interest in Hubble's research on the distance and velocity of galaxies. In 1927 he proposed an early version of the Big Bang Theory. He also showed that the concept of an expanding Universe agreed with Einstein's Theory of Relativity.

Allan Sandage (1926–2010) The astronomer who took over Hubble's research in 1953. He fine-tuned the use of Cepheids for the determination of the Hubble Constant, arriving at an age of the Universe that did not conflict with the age of certain stars or the Earth itself.

TIMELINE

The observations, discoveries and theories that shaped our picture of the Universe today

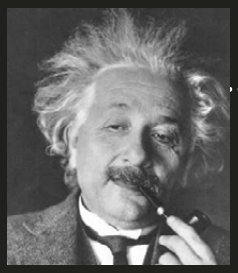


1912 — **Henrietta Leavitt** discovers that the intrinsic luminosity of a class of variable stars, known as Cepheids, is related to their variation period.

1923 — **Vesto Slipher** publishes a list with the redshift of 41 nebulae, showing that 36 nebulae are moving away from us.

1924 — **Edwin Hubble** measures the distance of Cepheids in the Andromeda Nebula and infers that this nebula and other similar systems are, in fact, distant 'Milky Way systems': that is, galaxies like our own.

1927 — **Georges Lemaître** shows that Einstein's theory of General Relativity supports the expansion of the Universe.



1929 — **Edwin Hubble** publishes his discovery that galaxies speed away from us at velocities proportional to their distances.

1965 — **Arno Penzias** and **Robert Wilson** publish their discovery of the cosmic background radiation. Its existence had been predicted by Robert H Dicke in 1964.

PHOTO: ESO, NASA X2, SCIENCE PHOTO LIBRARY X2, PRESS ASSOCIATION

He then searched in older photographic plates of the nebula and discovered 11 more novae inside it. This was more than all the novae observed in the rest of the Milky Way during the same period. Curtis decided that the Andromeda Nebula and similar observed nebulae had to be distant galaxies similar to our own.

In 1920, Curtis defended this idea in the 'Great Debate' with Harlow Shapley, who maintained the idea that the observed nebulae had to be inside our Galaxy, and were in fact small objects. Shapley, who used Cepheids to estimate the size of the Milky Way Galaxy, argued that if the Andromeda Nebula were comparable in size to the Milky Way, it would be at an enormous distance, an idea quite unthinkable to astronomers at that time. Also, a nova explosion that would outshine an entire galaxy was inconceivable.

In 1917, George Ellery Hale installed the 2.5m Hooker Telescope at the Mount Wilson Observatory, which was the world's largest until 1948. In the early 1920s, Edwin Hubble used it to observe several Cepheid variables in the Andromeda Nebula and other spiral nebulae, and found they were far outside the Milky Way. This discovery confirmed Curtis's hypothesis that these nebulae were in fact galaxy systems beyond our own.

However, when Hubble determined their distances using Leavitt's period-luminosity relationship and compared them with the redshifts of 41 nebulae determined by Slipher in 1925, he found an astonishing fact: the farther the galaxy, the larger its redshift, and therefore its velocity away from us. As a result of his findings, in 1929 he formulated Hubble's Law, stating that the velocity of separation between any two galaxies is proportional to their distance from each other. The proportionality factor is called the Hubble Constant. This finding became the first direct, observational evidence that the Universe is expanding.

In the meantime, a Russian and a Belgian, Alexander Friedmann and Georges Lemaître, both mathematical physicists, argued that Einstein's theory of General Relativity should dispense with the cosmological constant, and that the theory in fact predicts an expanding Universe. Einstein at first rejected this idea, but accepted it in 1933. Lemaître also came up with a cause of the expansion: the Universe started with the explosion of

NEED TO KNOW

Key astronomical terms and concepts explained

1 Hubble Constant
The rate of expansion of the Universe: it is the proportionality constant between the recession velocity of a galaxy and its distance and is expressed in km/s per Megaparsec. Edwin Hubble's initial determination of the Hubble Constant was 500 (km/s)/Mpc. Today's accepted value is around 74 (km/s)/Mpc.

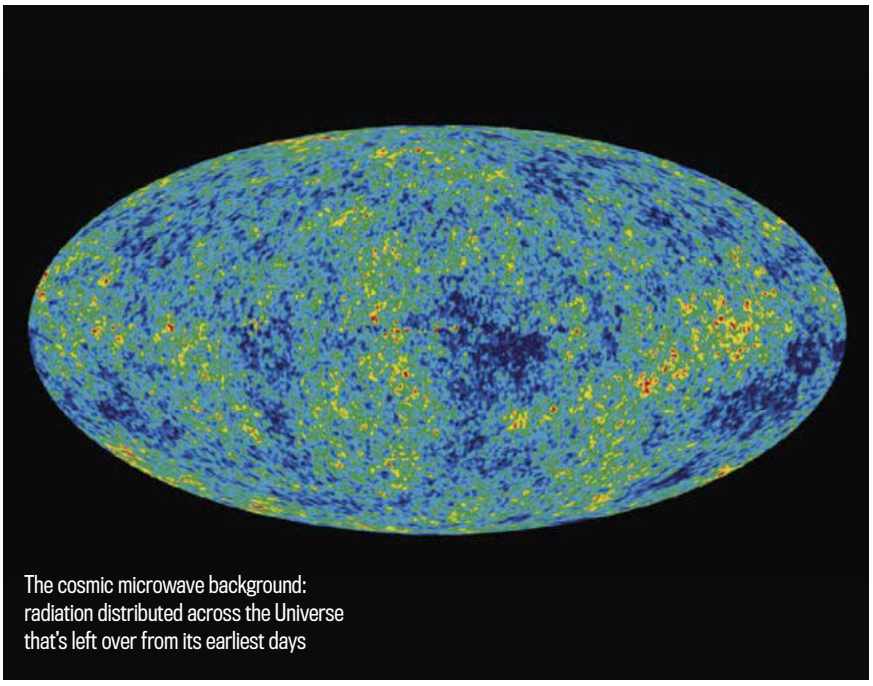
2 Redshift
The stretching of light waves emitted by a body moving away from us. Redshift is determined by the displacement of spectral lines in the spectra of these objects towards longer wavelengths – that is, the red end of the spectrum.

3 Spectrum
Just like the Sun, stars and galaxies radiate light that you can split into the colours of the rainbow, called the continuum, by passing it through a prism or a spectroscope. Atoms add bright or dark spectral lines to this continuum, allowing their identification.

4 Supernova
The powerful nuclear explosions of stars when they reach a certain age and collapse. Formerly only known as novae, the stellar explosions in distant galaxies that are visible are called supernovae.

a concentration of matter and energy, which he called the 'cosmic egg' or 'primeval atom'. This explosion later became known as the Big Bang, a term coined by British astronomer Fred Hoyle in 1950.

The idea that the Universe started with an explosion was interesting because it allowed the estimation of its age, simply by calculating the time each galaxy had taken to cover the distance at which it is now observed. However, when astronomers started calculating the time the galaxies had spent travelling, they found that the Universe should be two billion years old. This caused a problem because there was already evidence that Earth itself was at least two billion years old.



The cosmic microwave background: radiation distributed across the Universe that's left over from its earliest days

This discrepancy encouraged British astronomers Fred Hoyle, Hermann Bondi and Thomas Gold to propose an alternative, the Steady State theory. They accepted that the Universe is expanding, but argued that the expansion is caused by the continuous creation of new matter and galaxies in the space that is opening up between existing galaxies.

A NEW MYSTERY

The Steady State theory came under increasing criticism when improvements were made in the calibration of Cepheids as distance indicators. American astronomer Allan Sandage, who took over Hubble's research when he died in 1953, was able to show that the first estimates of the distances of receding galaxies were too low. New calibration results for the intrinsic luminosity of Cepheids showed that the galaxies had taken up to eight times longer to reach these distances, eliminating the conflict with the Earth's age. Today, the age of the Universe is set at 13.7 billion years old

However, the strongest evidence for a Universe that started with a Big Bang and is expanding came in 1964, with the observation of the 3K Cosmic Background radiation by Arno Penzias and Robert Wilson (see 'The Key Experiment', p90).

Cepheids as distance indicators can only be observed in galaxies that are relatively close, but certain supernovae (Type 1) produce a fixed amount of light. Because their brightness during the explosion is enormous, they can serve as distance indicators for very far-off galaxies. In 1998, groups led by Saul Perlmutter of Lawrence Berkeley National Laboratory in California and Brian Schmidt of the Mount Stromlo Observatory in Australia, found the apparent brightness of these supernovae was lower than expected in galaxies for which the distance was determined by their redshift alone.

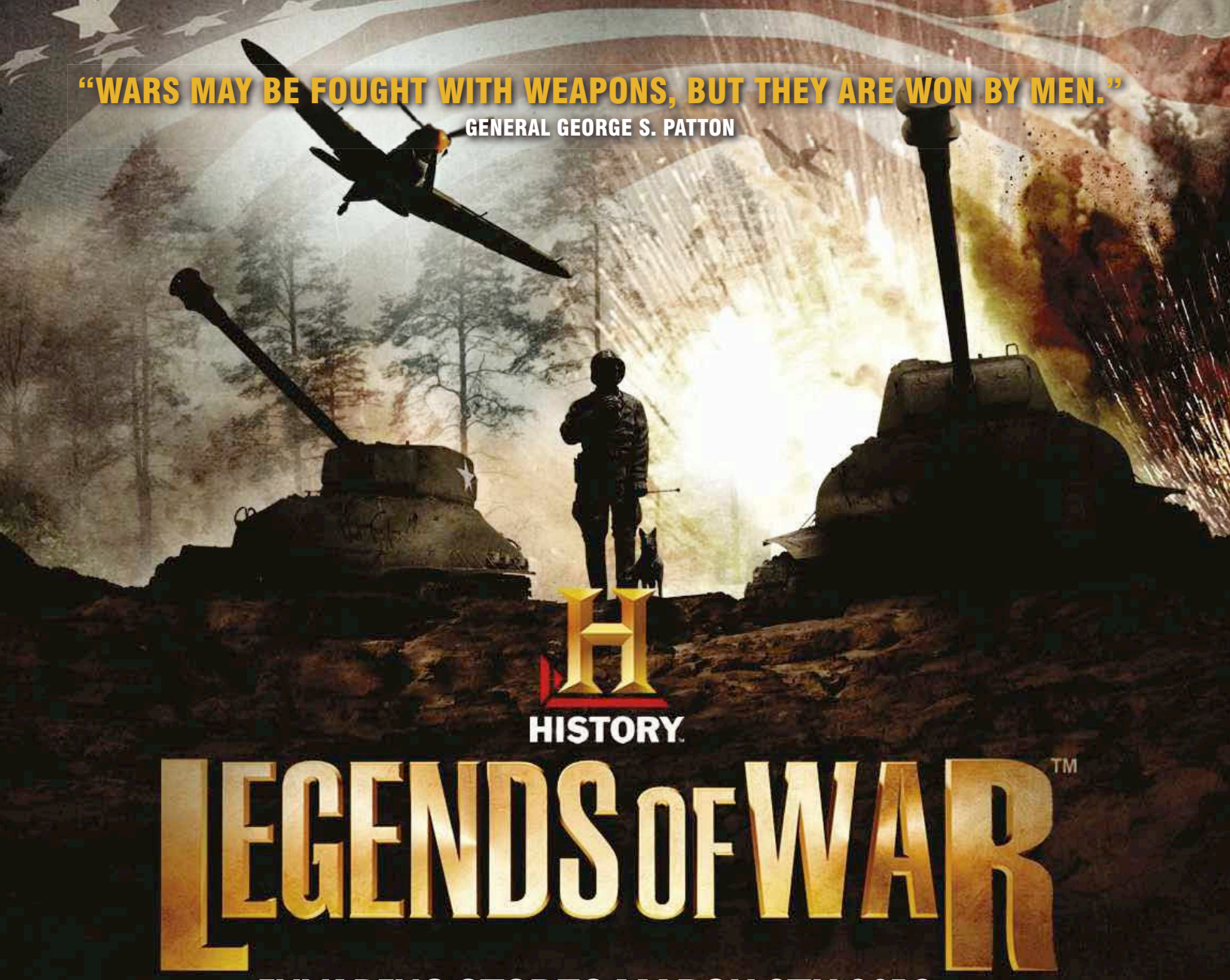
The astronomers concluded that the expansion of the Universe is speeding up, and that this acceleration of the expansion must be driven by a still unknown form of energy, termed dark energy. Many astronomers now expect that the elucidation of this mystery may result in a new revolution in our understanding of the Universe. ■

Alexander Hellemans is a science writer and co-author of *The History Of Science And*

Find out more

http://bbc.in/hMLCE6 A 2011 episode of *In Our Time* in which Melvyn Bragg discusses the age of the Universe with Sir Martin Rees

http://bbc.in/SD88WP More on Hubble's Law from the BBC Science website



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PICK OF THE MONTH

Extinction: Not The End Of The World?

Come face to face with the now extinct giant Irish Elk at the Natural History Museum

WE'RE GOING TO a lot of trouble to stop the panda becoming extinct – more trouble, it sometimes seems, than the pandas themselves. But once a species has gone, it's gone forever. So it seems a pity to lose the bumbling, black and white, bamboo-eating bears even if they can't be bothered to reproduce or try varying their diet a bit.

However, as the Natural History Museum's major new exhibition 'Extinction: Not The End Of The World?' reveals, over 99 per cent of all the species that ever lived on Earth have gone extinct. Extinction is a natural process, an essential part of evolution. Without it, there'd be no room for new species to emerge. Mass extinctions like that which wiped out the dinosaurs made way for new animals, plants and microbes.

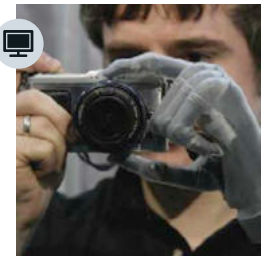
The exhibition aims to cover the rich history of extinction by showcasing the many species that have ceased to exist. Drawing from the museum's rich collection, you'll find the fabled dodo, the massive head and antlers of the Irish Elk and come face to face with the skull of *Chasmosaurus belli* – one of the last dinosaurs to have walked the Earth. There's also a chance to celebrate the creatures that have stood the test of time such as the leatherback turtle, which has been around for 100 million years. Around 80 specimens will be on display alongside interactive installations and images from the Natural History Museum's rich archive. Find out what makes the difference between extinction and survival, and what we can do to protect today's endangered species.

Like other successful species before us, we have eaten tasty rivals into extinction and destroyed habitats, but, as this exhibition asks, might we become extinct ourselves?

TIMANDRA HARKNESS

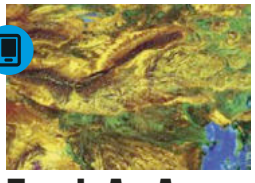
Extinction opens on 8 February at the Natural History Museum. £9/£4, free for members and children under 4, www.nhm.ac.uk, 020 7942 5000

DON'T MISS!



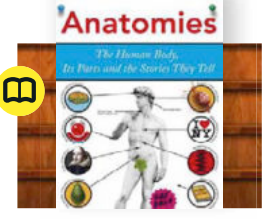
How To Build A Bionic Man

Psychologist Bertolt Meyer ponders the ethical issues raised by new advances in prosthetics. p98



Earth As Art

A collection of stunning satellite images collected by NASA since the mid-1970s. p100



Anatomies

Dr Michael Mosley reviews Hugh Aldersey-Williams's title, which demystifies the human body. p102

PHOTO: NATURAL HISTORY MUSEUM

VISIT

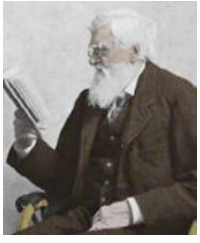
EVENTS & EXHIBITIONS

WITH JHENI OSMAN

FEBRUARY-NOVEMBER

Wallace100

Natural History Museum, London, www.nhm.ac.uk/wallace100



WHILE CHARLES DARWIN is remembered for discovering the theory of natural selection, we must not forget the vital role played by Alfred Russel Wallace. To mark the centenary of his death, the museum is running a programme of events and activities. Join one of the monthly talks by eminent scientists, such as 'Wallace And The Flat Earth Controversy' on 5 March, or come the summer, look out for the Wallace Discovery Trail around the museum.

16 FEBRUARY

We Made It: Nuts, Bolts, Gadgets And Gizmos

Thinktank, Birmingham, £11/£7.50 (advance), www.thinktank.ac

BIRMINGHAM HAS A rich manufacturing history, from the medieval crafts of textiles, leather and ironworking, through to its armouries and chocolate-making factory. This hands-on gallery, showcasing over 1,200 objects from raw materials to finished products, explains the science behind the materials and manufacturing processes that once made the city the 'workshop of the world'.

19 FEBRUARY

What On Earth Is That?

Natural History Museum, London, 12.30pm and 2.30pm, free, www.nhm.ac.uk/nature-live

EVER FOUND A fossil, bone, rock or tooth lying around on a beach or in the woods, and wondered what it was? Bring along your mysterious treasure to this event, and Natural History Museum's scientists will help you discover what creature it belonged to or where it came from. There will also be the chance to have a go at working out what's a meteorite and what is simply a boring old rock. It's harder to figure out than you might think!

JHENI OSMAN is a science writer and the author of *100 Ideas That Changed The World* (BBC Books, £9.99)

EDITOR'S CHOICE

Dave resorted to desperate measures in a bid to distract attention from his tie-dye shirt

14-17 MARCH

The Big Bang Fair

London ExCel, free, www.thebigbangfair.co.uk

AT THIS TRULY epic young people's science fair, which returns for its fifth year running, some of the country's leading scientists will be on hand to answer questions. But there are also over 100 activities, exhibitions and live shows to give budding engineers and scientists a taste of the future.

Explore the wacky science of the circus, zombies and insect birth control. Learn about life at the extremes, or live on the edge yourself in Gastronaut Live! by tasting radioactive soup. If you're not the squeamish type, you can have a go at taking blood, or try to figure out whether a laugh is fake or real in LOL: The Science Of Laughter.

Find out how fusion power works, or take control of a virtual nuclear reactor and discover how to avoid a Fukushima-like disaster. Hop aboard the RNLI's Lifeboat Lab, or explore the most advanced infrared space telescope, Herschel. For maker types, there's the chance to print in 3D, weld with chocolate, construct the tallest tower possible, or design and build your own miniature all-terrain vehicle.

The fair's even got its own 'natural history musical', From Amoeba To Zebra. So whether you're a maths whizz, wildlife lover, home brewer or garden-shed inventor, there's something for everyone at this action-packed event.

23 FEBRUARY

The ALMA Telescope

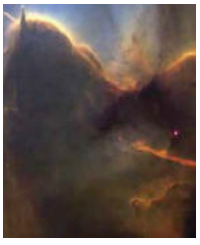
MOSI, Manchester, free, 10.30am–3.30pm, www.mosi.org.uk

THIS ARRAY OF telescopes in Chile's Atacama Desert is due to be completed this year. Already partially functional, it has captured images of stars forming from interstellar gas, discs of dust around other stars, and even very distant galaxies near the edge of the observable Universe. See some of the latest astronomical images from ALMA, and try your hand at producing images from multiple antennae.

EARLY MARCH

Alien Revolution

Royal Observatory Greenwich, London, until August, free, www.rmg.co.uk



DISCOVERIES OFTEN HAPPEN when someone dares to think the unthinkable, as Copernicus did when he proposed that the Earth orbits the Sun. Within a century, people believed in an infinite Universe crawling with intelligent life. This exhibition, part of the Royal Observatory's Alien Season, examines this little-known 'alien revolution' and how our ideas developed about aliens in science and culture.

5 MARCH

Greening Up Our Cities

Jekyll And Hyde, Steelhouse Lane, Birmingham, 7pm, free, www.thinktank.ac/cafe_sci

OUR PLANET COULD have to carry up to 10 billion people later this century. Cities are our best hope for accommodating everyone, but concrete jungles create their own problems. At this Cafe Scientifique event, Prof Rob McKenzie from the University of Birmingham discusses the role urban plants can play. He also reveals how greenery can do more harm than good if planted in the wrong place.

19 MARCH

Evgeny Morozov – To Save Everything, Click Here

Watershed, Bristol, 6.15pm, £7/£6, www.ideasfestival.co.uk

DO YOU THINK technology is becoming increasingly pervasive? Acclaimed author Evgeny Morozov discusses how tech isn't just making it easier to do things like add a digital diary event for great talks, but the face of society and the nature of human behaviour itself. It forms the subject of his new book and is a must if you want to see where we're heading in the near future.

SPEAKER OF THE MONTH

19 FEBRUARY

Ben Goldacre

At-Bristol, Bristol, 7pm–8pm, £7/£6, www.ideasfestival.co.uk

Who is he?
A doctor, writer and broadcaster whose work delves into dodgy scientific claims from the media, government and other bodies. His first book, *Bad Science*, has been translated into 25 languages.

What's his background?
Goldacre is the son of Michael Goldacre, an Oxford University professor, and '70s pop star Noosha Fox. He studied medicine at Oxford and at King's College, London.

What's he talking about?
His new book, *Bad Pharma: How Drug Companies Mislead Doctors And Harm Patients*. With tales of bribes for medics and other foul play, expect an eye-opening talk followed by a book signing.

UNTIL 9 MARCH

Transformism

John Hansard Gallery, University of Southampton, free, www.artscatalyst.org

INVESTIGATING THE FRONTIERS of bioscience and its impact on our beliefs and understanding, this exhibition features works by two artists. Using a range of tools and techniques, Melanie Jackson explores nanoscience, synthetic biology and biomimicry through sculpture and film, while Revital Cohen looks at creatures that have been designed for aesthetic purposes, asking if a manipulated organism is an product, animal or pet? This unusual exhibition is certain to spark plenty of discussion.

WATCH

TV, DVD, BLU-RAY & ONLINE

WITH TIMANDRA HARKNESS

FEBRUARY

Beat The Ancestors

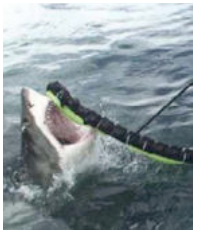
Channel Five, February, dates/times TBC

EVERYONE'S FAVOURITE MOUSTACHIOED technophile Dick Strawbridge fronts this unusual take on historical machinery. Teams of engineers take on the challenge of reconstructing ancient gadgets, such as a Byzantine fire boat and Churchill's rocket parachute, and then try to improve them. Will our modern understanding of scientific principles allow them to update and refine the designs? Or will they be left even more in awe of what our ancestors managed to achieve with the resources they had?

11-17 FEBRUARY

Shark Week

Animal Planet, 11-17 February, 9pm



IT'S THE RETURN of the annual fish-fest with more bite than a bidet full of piranhas, from *Great White: The Impossible Shot*, in which veteran wildlife camera crews try to film a great white shark, to *Sharkzilla*, the on-screen resurrection of Megalodon, the biggest shark ever to swim Earth's oceans. You can also enjoy the story of three war heroes who spent 47 days adrift in shark-infested waters, and the touching tale of shark attack victims who nevertheless defend marine wildlife vehemently – even when it's the very sharks that bit them.

18 FEBRUARY

Biggest And Baddest

Animal Planet, starts 18 February, 9pm

BRITISH EXPLORER AND wildlife expert Niall McCann goes in search of the world's wildest, scariest beasts in this new six-part series. And just in case a man wrestling with anacondas and being charged by tigers isn't interesting enough, he's equipped with scientific equipment to study them, too. Watch him take DNA samples from wild hogs and measure marauding elephants with lasers. That's McCann who has the lasers, not the marauding elephants – though that would have made the series even better...

TIMANDRA HARKNESS is a stand-up comic and presenter on the BBC's HeadSqueeze YouTube channel.

Psychologist Bertolt Meyer questions our bionic future

7 FEBRUARY

How To Build A Bionic Man

Channel Four, 7 February, 9pm

EVER SINCE MARY Shelley's *Frankenstein* imagined a man-made human, the thought of assembling a person from scratch has both intrigued and appalled us. But as medicine and engineering advance, the idea draws closer to being a practical reality. We can already replace hips, knees, eyes, limbs and even parts of our mental function. Now, psychologist Bertolt Meyer presents this ambitious attempt to create an entire working human body.

Unlike Dr Frankenstein, Meyer's team is working not with natural body parts, but with the kind of technology showcased at the Paralympics. Carbon fibre limbs, electronic eye implants, artificial hearts and organs grown from stem cells are all designed to replace part of a functioning human body. But how far could we go in superseding our natural flesh? Meyer himself has a bionic hand, so he's well placed to explore the strange frontiers of what is sometimes called transhuman existence.

As over $1 million worth of experimental technology is borrowed, donated and built, and Meyer's bionic man becomes a disturbing reality, new questions arise. How much of you could be replaced before you ceased to be you? Is it okay to restore normal function, but not okay to give somebody superhuman abilities? And what are the limits to treating our bodies like cars, simply replacing parts as they wear out?

The Science Museum in London will display the finished bionic man in a new free exhibition funded by the Wellcome Trust, entitled How Much Of You Can Be Rebuilt?

PHOTO: CHANNEL 5 TELEVISION, TOUCH BIONICS, DISCOVERY NETWORK X3, NATIONAL GEOGRAPHIC CHANNEL X3, CHARLES J SHARP

FROM 21 FEBRUARY

How To Grow A Planet

Eden, starts 18 February, 9pm

PROFESSOR IAIN STEWART is best known for bringing geology to our screens, but in this series he looks at another force that has shaped our planet and its atmosphere: the plant kingdom. Without plants' ability to turn the energy of sunlight into sugars and oxygen, animal (including human) life would be impossible. But the story is more complex than that. Flowers aren't only essential to romance, they facilitated animal evolution in deepest prehistory, too. And the humble grasses are central to stories from fire to civilisation itself.

FROM 21 FEBRUARY

Earthflight

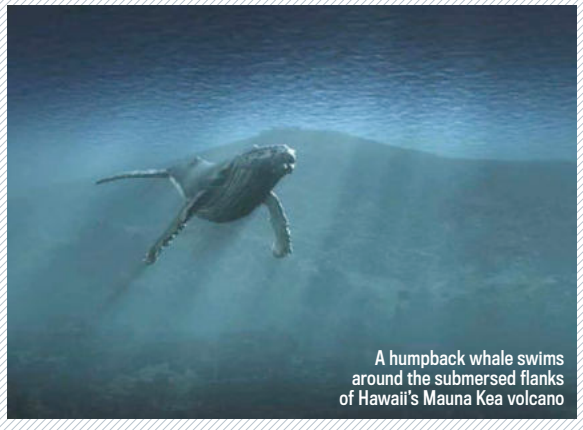
Eden, starts 21 February, 8pm

EVER WANTED A bird's eye view of the planet? Then this is the series for you. Originally aired on BBC One, *Earthflight* allows you to migrate with snow geese and fly with pelicans under San Francisco's Golden Gate Bridge. Along the way, there is much to learn about bird life: how to avoid predators, where to look for food, and why you should follow a humpback whale. If you're a pelican, that is.

2 MARCH

Alien Deep: Fires Of Creation

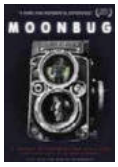
National Geographic, 2 March, 8pm



A humpback whale swims around the submersed flanks of Hawaii's Mauna Kea volcano

HELD BACK FROM the main *Alien Deep* series to form part of National Geographic's *Explorer 125* season, this film follows Dr Robert Ballard not up but down the world's tallest mountain. Hawaii's Mauna Kea rises 4,206m (13,800ft) above sea level, but also plunges 6,004m (19,700ft) below. Deep ocean volcanoes like these played a still-mysterious role in the development of life on Earth. Ballard's team penetrate this hostile world in two submersibles, entering the volcanic heart of Hawaii and capturing it in 3D for the first time.

DVD & BLU-RAY



Moonbug

Good Guys Media, £9.70

STEVE PYKE IS on a mission to photograph the original Apollo astronauts. This documentary tells the story of how he tracks them down and records their portraits – and their memories – on film. Alongside his journeys, there's also lots of archive footage of NASA's Moon missions. Winner of the Special Jury Prize at the Houston International Film Festival, the film features an original score by Matt Johnson and The The.

Africa

BBC, £17.99

THIS IMPRESSIVE FIVE-PART series is now on DVD. From coast to mountain, jungle to desert, survey the varied landscape of the wild continent and meet the wildlife: exploding insects, lizards that hitch lifts with lions and many others. Using the latest filming techniques to capture the most elusive creatures, this is classic Attenborough.

A Century Of Steelmaking On Film

British Film Institute, £18

FOR CENTURIES, STEEL has been central to British engineering. This two-disc box set from the BFI brings together footage from 1901 to 1987: highlights include a 1945 colour film showing the steelmaking process from ore to steelworks, alongside short films, documentaries and animations. A great resource for industrial historians.

FROM 9 MARCH

Saving Egypt's Oldest Pyramid

National Geographic, 9 March, 8pm

PHARAOH DJOSER WAS interred in the Step Pyramid at Saqqara 5,000 years ago. Now, shaken by earthquakes, eroded by sandstorms, looted and in danger of collapsing, his tomb is the subject of a rescue mission. A team of Egyptian and British experts has been working for five years, but their efforts are now complicated by Egypt's political turmoil.

FROM 20 MARCH

Breaking Magic

Discovery, starts 20 March, 8pm

WITH STREET MAGIC, hidden cameras and spectacular stunts performed by a bunch of rising stars, this new series has all the ingredients of an entertaining magic show. But there's a twist: underlying every trick is pure science. So after turning silver into gold, telling lies from truth, or stopping a cannonball, the team will explain exactly how it's done. Ben Hanlin, Billy Kidd, Wayne Houchin and James Galea travel the world to astonish, intrigue and educate us.

LISTEN

BBC RADIO PROGRAMMES

WITH TIMANDRA HARKNESS

4 FEBRUARY

Discovery: Sexual Nature

BBC World Service, from 4 February, various times

ADAM RUTHERFORD KNOWS all about sex. When it was invented (apparently not in 1963 – sorry Philip Larkin), why it's so popular and how it helps evolution. And in these three programmes he'll reveal everything. Meet the fossil turtles frozen *in flagrante*, the lady lizards who opted for virgin birth instead, and the fish who switch sexes.

19 FEBRUARY

The Listeners

BBC Radio 4, 19 February, 11am

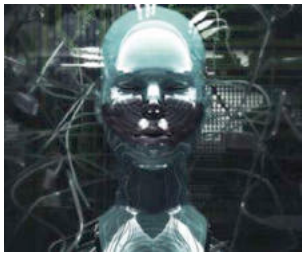
Listening is what we all do when we turn on the radio, right? But this two-parter tells a more complex story, as it introduces us to some professional listeners. The first show includes people who use listening devices to seek signs of life. The second moves on to even more esoteric listeners – those whose attention is on sounds normally beyond the limits of human hearing.

25 FEBRUARY

What If... We Were All Cyborgs?

BBC World Service, 25 February

THE *WHAT IF...?* season continues with a range of programmes and online content about the future. This one looks at human augmentation, and asks how far we could go. Recent advances already throw up ethical dilemmas. As our powers to transform ourselves increase, do we become less human?



Your grandchild might end up like this!

4 MARCH

What If... We Could Stay Forever Young?

BBC World Service, from 4 March

PEOPLE ALREADY WORK out, go on diets, undergo surgery and get themselves injected with toxins to stave off the outwards signs of getting older. How much more would we do to stay young? Peter Bowes reports from LA on the extremes of the quest to preserve physical perfection. Three radio programmes, online documentaries and a TV film explore the stranger frontiers of anti-ageing research.

7 MARCH

Who's The Pest?

BBC Radio 4, from 7 March, times TBC

INSECTS ARE LITTLE-LOVED. Ants or wasps can ruin a picnic, while for farmers and gardeners insects are the cue to reach for the pesticide. Yet they play vital roles in our lives, and their own lives are complex, even beautiful. This three-part series asks whether we can ever live in harmony with insects.

TOUCH

SMARTPHONE & TABLET APPS

WITH CHRISTOPHER PHIN

NASA Earth As Art

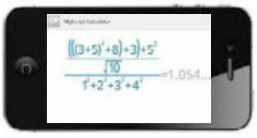
iPhone, iPod Touch, iPad
NASA, free

LANDSAT 5 STARTED orbiting Earth in 1984, capturing images of tsunamis, forest fires, oil spills and more. Now, as it's being decommissioned, NASA has launched a book and app featuring some stunning photos shot by the satellite and its orbiting chums Landsat 7, Terra, EO-1 and Aqua. Though the app itself is a little plain, and the information about each shot not as detailed as we'd have liked, you can lose yourself in the images – showing phenomena such as gravity waves as well as beautiful vistas – for hours.

GyroSpace 3D Live Wallpaper

Android 2.1 or later
Opotech, £1

THIS APP REPLACES the wallpaper on your Android phone or tablet with a view of the Earth or another planet... which sounds rather dull, until you learn that it uses your device's gyroscope to rotate the view live as you turn it. It's a pleasingly disconcerting effect, as are the meteoroids silently tumbling across your view. It works well, it's just a shame that the view is fake – it would be brilliant if the Earth had live cloud cover, and the constellations were in the right place.



MyScript Calculator

iPhone, iPod Touch, iPad
Vision Objects, free

Throw away your calculator. This wonderful app lets you scribble down calculations using just your finger, and pops out the right answer. Its handwriting recognition is excellent, and it supports a broad range of operators – exponentials, trigonometry, logarithms, square root and more. It's a great way to express calculations naturally, and once you've written one down, you can even edit it, correcting mistakes with a simple scribble gesture, or augment it, for instance by enclosing it in brackets to do something else to the result.

CHRISTOPHER PHIN is the editor of *MACFORMAT* magazine

PHOTO: THINKSTOCK

PLAY

CONSOLE & COMPUTER GAMES

WITH NEON KELLY

God Of War: Ascension

PS3, SCE, £39.99

WHY DO SO many games feature angry bald men in the leading role? There are countless examples, but few are as angry (or as bald) as Kratos, antihero for the *God Of War* series. Like its predecessors, *Ascension* resembles *Clash Of The Titans* as directed by Quentin Tarantino – a thrilling but ultra-violent action romp through a catalogue of Greek mythology. This instalment boasts a new eight-way multiplayer mode, but blockbuster spectacle remains the key draw.

StarCraft II: Heart Of The Swarm

PC, Blizzard, £29.99

BLIZZARD'S *STARCRAFT II* is a monument to the real-time strategy genre and the focal point for an international community of professional (yes, they get paid) gamers. It's a game so huge that Blizzard had to divvy it up into three chunks. While 2010's *Wings Of Liberty* focused on the Terrans (space-faring rednecks, essentially), here the focus is on the insectoid Zerg. There's an epic narrative campaign, but it's the expansive multiplayer that will hijack your life.

Rayman Legends

Wii U, Ubisoft, £39.99

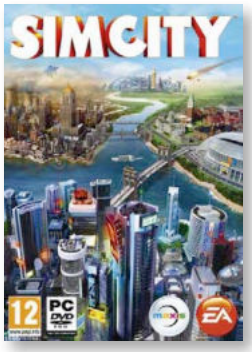
DESPITE BEING A rare survivor from the era of vintage platform games (ie the 1990s), *Rayman* has always skulked in the shadow of *Mario* and other A-list icons. That's no fault of his own though, and *Legends* is another classic helping of old-school acrobatics for up to four players. The hand-drawn graphics here are swooningly beautiful, but don't be fooled: while *Rayman Legends* is arguably the best-looking game on the Wii U, it's also fiercely challenging. Child's play this is not.

NEON KELLY IS DEPUTY EDITOR AT VIDEOGAMER.COM

Sim City has never looked so good, with a cool 'tilt-shift' photographic effect used to make even the dingiest parts of your metropolis look stunning

Sim City

PC, EA, £39.99



AS MUCH AS we all like to take a pop at the Boris Johnsons and Ken Livingstones of this world, how many of us would be eager to step into their shoes? Sure, there's the power and prestige of running a major city, but think of all the downsides – the stress, the bureaucracy, the endless stream of journalists who relentlessly make fun of your silly haircut.

Sim City circumvents many of these problems by turning the player into an omnipotent God of Town Planning. Here you get to run the show, without any of the drudgery of actually being a real mayor. In the beginning your city is nothing but a patch of vacant scrubland. You pick a location and then hook it up to the main road that leads to the rest of the world. Build a few factories and civilians show up to nab the resulting jobs. Give them places to live and maybe a few shops so that they can buy the things they need... and then what? Perhaps a station might encourage tourists to visit? Build a museum? Or, wait – put in a casino!

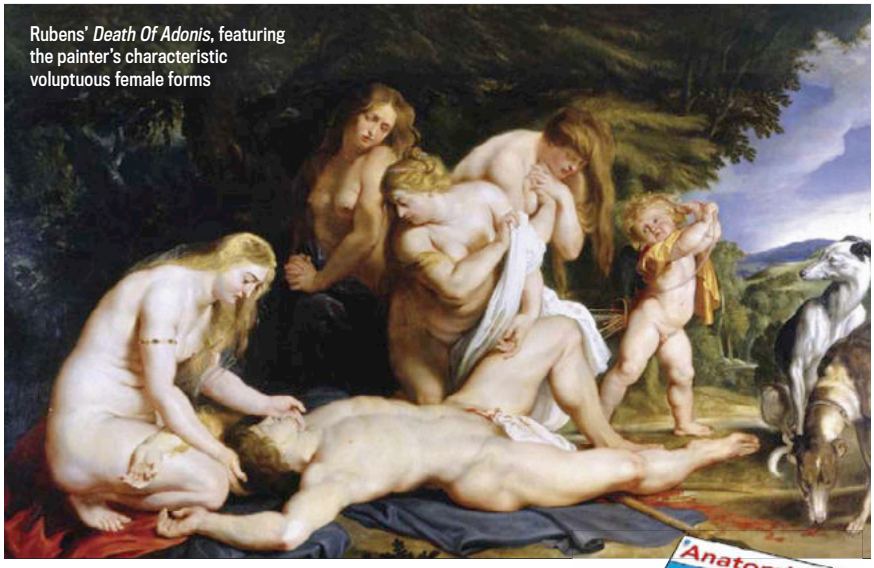
That's what happens with these *Sim City* games. Everything is oh-so-simple at the start, but before you know it, your harmless little town has sprawled into a complex metropolis. You've got airports, observatories and skyscrapers. Unfortunately, you've also got a serious crime problem. Your lonely wind farm isn't enough to power up your financial district, and because you neglected your sewage works, toxic waste is poisoning your suburbs. Oh, and aliens have started abducting your civilians.

Still, even when everything is going to pot, *Sim City* is heartbreakingly charming. New buildings gradually sprout into existence, telescoping upward as if springing up from the pages of a pop-up book. And when dusk falls upon your fledgling city, tiny lights illuminating every stretch of road, you'll simmer with silent pride – that is if you remembered to build enough wind farms to power the lights.

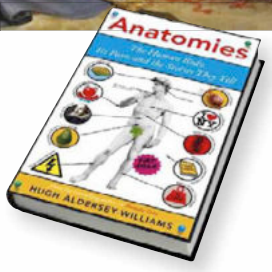
READ

THE LATEST SCIENCE BOOKS REVIEWED

H Hardback P Paperback



Rubens' *Death Of Adonis*, featuring the painter's characteristic voluptuous female forms



Anatomies

The Human Body, Its Parts And The Stories They Tell

Hugh Aldersey-Williams
Viking H £18.99

I AM A great admirer of human bodies. They are magnificent, complex, endlessly fascinating biological wonders. Yet we drive them hard, take them for granted and remain largely ignorant about how exactly the different parts function. I was therefore delighted to lay my hands on Hugh Aldersey-Williams' latest book, *Anatomies*. The best-selling author of *Periodic Tables* admits in the introduction that he knows shamefully little about how his own body works, then sets out to try and fill in some of the gaps in his knowledge.

This, though, is not a detailed account of bones or the blood; it is a journey through history and literature, looking not just at what the body does, but at what it has meant to writers, artists and thinkers. So the chapter 'Flesh' starts with a discussion of Shylock in *The Merchant Of Venice*, a moneylender who famously demands a pound of flesh from the merchant, Antonio, when he fails to repay a loan. As the author points out, this forfeit has "echoes of legally sanctioned punishment by amputation". If you were wondering how much a pound of flesh actually is, then apparently a heart dripping with fresh blood would come in at around that, or a hand amputated a few inches above the wrist.

Then we are off, via Peter Paul Rubens, the painter of voluptuous, fleshy nudes, to a stomach-churning story of a food writer who converts fat extracted from his body through liposuction into glycerol, which he uses to ice a cake. The author rounds off this enjoyably gruesome chapter with a reason to cherish our love handles – research which shows that human fat may in future be a useful source of stem cells.

I finished the book and sat back feeling great affection for my own body, my home. As this book rightly concludes, it's quite a remarkable place.

■■■■■

MICHAEL MOSLEY is a writer, doctor and BBC science presenter

MEET THE AUTHOR

Hugh Aldersey-Williams

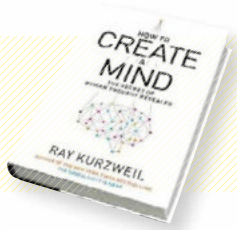
Why did you write this book?
The book's about how we understand the body, or perhaps how we're forgetting to understand the body. In a way, it's a bit of an antidote to books about genomics and the 'genes are us' approach to things. Reducing the human body to strings of letters and numbers is useful for scientists but it's not something that helps most of us, who have this bag of skin containing a load of organs that somehow miraculously all work together. How we understand our body and what we believe about it is very much coloured by our long cultural history.

What was the most challenging aspect of writing the book?
I wanted to go and see some anatomy classes, but it's actually very difficult for unqualified people to get into them. Eventually, I did manage to get onto a course where first year students at the Ruskin art school were drawing from anatomy – the only art school left in the country that still does this. Drawing from dead bodies was a way that all artists used to train.

Was seeing a dead body quite an unnerving experience?
I suppose I had some trepidation on my long drive over there that morning, and when I met up with the students, who'd only studied plastic skeletons before, there was a certain amount of gallows humour among them. But it's a clinical environment – it's all very bright and ordered and clean – and that gives it an atmosphere that's not at all grotesque. So I learned that a dead body's not as scary as you might think.

MORE ON THE PODCAST
Listen to the full interview on the podcast at sciencefocus.com/podcasts

PHOTO: BRIDGEMAN ART LIBRARY



How To Create A Mind

The Secret Of Human Thought Revealed

Ray Kurzweil

Duckworth Overlook (H) £20

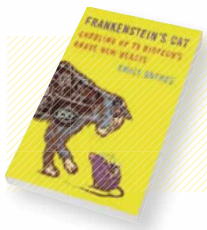
BRAINS AREN'T AS complicated as you think. At least, so says Ray Kurzweil in his controversial new book. For this outspoken futurist, pattern recognition is all that counts. "If understanding language and other phenomena through statistical analysis does not count as true understanding," he argues, "then humans have no understanding either."

In his latest book, Kurzweil delves into the topic in some detail, giving his own take on the history of AI and neuroscience as he attempts to describe how he would build intelligence into a computer. He is most convincing when describing his own successes, such as helping to develop the voice recognition methods used in Siri, but then it is not Kurzweil's aim to be impartial. This book is written with the clear agenda of prophesizing the Kurzweil vision: we'll apparently have conscious computers by 2029 and will be able to scan and upload our brains by 2040.

How To Create A Mind is classic Kurzweil: at times fascinating and insightful, at times absurd and deluded. He may have decades of experience in the topic, but the secret of human thought is not contained in the pages of this book.

■■■□□

DR PETER J BENTLEY is author of *Digitized* and an Honorary Reader at UCL



Frankenstein's Cat

Cuddling Up To Biotech's Brave New Beasts

Emily Anthes

Oneworld (P) £11.99

THE CURRENT ROSTER of pets *chez* Gee includes two dogs, two snakes, four cats, several fish, a rabbit, 15 hens and an axolotl. All these creatures have been bred in captivity and are substantially different from their wild cousins; indeed, axolotls are highly endangered in their native Mexico. Human alteration of animals, for good or ill, has been going on for thousands of years and is well advanced. But can we go further? And should we? This is the theme of Emily Anthes' charming book.

Starting with GM pet fish that glow in the dark, she moves on to the theory and practice of cloning animals as livestock, bloodstock and pets, using animals as generators of novel pharmaceuticals – the eggs of frankenhens, or the milk from frankengoats – and veterinary surgery to give pets prostheses, or to turn animals into sensors for military surveillance.

The science is accessible and so, mercifully, is the ethics. How much modification of animals is acceptable, even if it will pay dividends for human welfare? Yes, there are weak points – there could have been more on xenotransplanation, for instance – but this is a breezy introduction to a complex and controversial issue.

■■■■□

HENRY GEE is a biologist, senior editor of the journal *Nature* and *Focus* columnist

The Scientific Sherlock Holmes

Cracking The Case With Science And Forensics

James O'Brien

Oxford University Press (H) £18.99

IN NEARLY ALL of the 60 Sherlock Holmes stories, the detective uses some form of what would now be recognised as 'forensic science'. This includes the use of fingerprints, footprints, handwriting examination, cryptology and even sniffer dogs. There are also many references to mathematics, biology, physics, astronomy and above all chemistry – in 2002, Holmes was posthumously made an Honorary Fellow of the Royal Society of Chemistry.

This book discusses in detail every scientific example that occurs in the 60 stories, pointing out their prescience and validity and illustrating their significance with reference to real cases in which such evidence was used. For example, we are told how Doyle demonstrated the possibility of collecting footprints with plaster of Paris, sniffer dogs and even fingerprints before they were in common use by the police.

For anyone who, like me, was sceptical of Holmes' (Doyle's) scientific credentials, this book is a detailed antidote. The depth of his knowledge puts to shame the superficial forensic psychology of today's fictional detectives.

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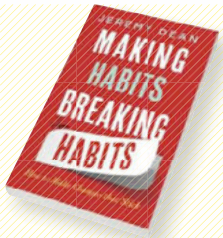
PROF DAVID CANTER is the author of *Forensic Psychology For Dummies*



Making Habits, Breaking Habits

How To Make Changes That Stick

Jeremy Dean

Oneworld (P) £8.99

HAVE YOU EVER tried to change a bad habit and failed? You should read this book. Learning that most of our behaviour consists of habits, and that familiar cues and places keep on reinforcing them, I've become much more aware of what I'm doing. This, it turns out, is a crucial step towards change. I was fascinated to learn that when good intentions are pitted against long-established habits, the habits usually win, and that when we are in pain or under stress we are more likely to fall back on them. Clearly, having the motivation to change is not enough.

Indeed, people's habitual behaviours are a much better predictor of what they will do in the future than their intentions. So we may *want* to eat less, exercise more or take up kayaking, but that isn't enough. We need 'implementation intentions' or 'if-then plans' with specific cues to prompt our new behaviours, and Dean tells us how to put these in place. Although his discussions of the 'unconscious mind' are rather simplistic, the book is highly readable, and I'm now feeling much more confident about starting my new exercise plan.

■■■■□

SUSAN BLACKMORE is the author of *The Meme Machine* and a *Focus* Q&A expert

FOCUS
SCIENCE AND TECHNOLOGY
APRIL ISSUE

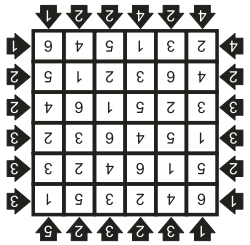
THINK BIG

VISIONARY IDEAS TO CHANGE THE WORLD... AND HOW SCIENCE COULD MAKE THEM HAPPEN

ON SALE 7 MARCH

PHOTO: GETTY

COMPETITION TERMS AND CONDITIONS:
Entrants must be UK residents (inc Channel Islands) aged 18 or over. Immediate Media employees are not eligible to enter. By entering participants agree to be bound by these terms and conditions and that their name and county may be released if they win. Only one entry permitted per person. No responsibility is accepted for lost, delayed, ineligible or fraudulent entries. The closing date and time are as shown on page 112. Entries received after that will not be considered. Entrants must supply their full name, address and daytime phone number. Immediate Media (publisher of *Focus*) will only ever use personal details for the purposes of administering this competition unless you permit otherwise. Read more about the Immediate Privacy Policy at www.immediatemedia.co.uk/privacy-policy. The winning entrants will be the first correct entries drawn at random after the closing time. The prize and number of winners will be as shown on the Crossword page. The winners will be notified within 30 days of the closing date by post. Immediate Media's decision is final and no further correspondence relating to the competition will be entered into. The name and county of residence of the winners will be published in the magazine within three months of the closing date. If the winner cannot be contacted within one month of the closing date, Immediate Media reserves the right to offer the prize to a runner-up.



MINDGAMES PUZZLE SOLUTION
No cheating! Don't look at this until you've attempted the puzzle on p111

A Startling Memory Feat That *You* Can Do

"How I learned the secret in one evening. It has helped me every day."

When my old friend Richard Faulkner invited me to a dinner party at his house, I little thought it would be the direct means of doubling my salary in less than two years. Yet it was, and here is the way it all came about.

Towards the end of the evening things began to drag a bit as they often do at parties. Finally someone suggested the old idea of having everyone do a 'party-piece'. Some sang, others forced weird sounds out of the piano, recited, told stories and so on.

Then it came to Peter Brown's turn. He said he had a simple 'trick' which he hoped we would like. First he asked to be blindfolded. Then he asked someone to shuffle a deck of cards and call them out in order. Still blindfolded he instantly named the cards in their order backwards and forwards without making a single mistake.

"There was really nothing to it – simply a memory feat"

On the way home that evening I asked Peter Brown how it was done. He said there was really nothing to it — simply a memory feat. Anyone could develop a good memory, he said, by following a few simple rules. And then he told me exactly how to do it. In one evening I made remarkable strides towards improving my memory.

What Peter told me that eventful evening was this: "Send for details of Dr. Bruno Furst's Memory Course." I did. That was my first step in learning to do all the remarkable things I have told you about. In fact, I was so impressed that I got permission to publish Dr. Furst's Course myself.

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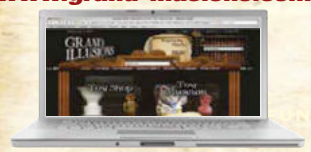

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SCIENCE FESTIVAL GUIDE

British Science Festival Newcastle 2013

The British Science Festival is going nutty about Newcastle this September. We will be gracing the Geordie shores with a science spectacular to remember from 7–12 September. With top minds in science heading east, make sure you don't miss out on this science fun. At the British Science Festival there really is something for everyone. An exciting programme of entertaining and engaging shows and spectaculars featuring artists, musicians and comedians. Eminent scientists including stars of the small screen, those at the forefront of today's technology and scientists searching for solutions to tomorrow's problems. The best the UK has to offer in science shows and workshops for school groups aged from 8 to 18. Fun for all the family around the city, whether you want to walk on custard or find out what dark matter really is, make sure you save this date!
The British Science Festival is presented by the British Science Association working in partnership with Newcastle University, Northumbria University and Newcastle City Council. Events will take place across the city including at the Centre for Life. Sign up for the British Science Festival newsletter to be the first to hear about all the exciting events.

7–12 September 2013
www.at-bristol.org.uk
☎ 08456 807 207

Orkney International Science Festival

World-famous sites provide an island setting for one of the world's oldest science festivals, with a reputation for continually probing the cutting edges of ideas. There is relativity and quantum theory, studies of the history of science; marine renewables, archaeology and art/science collaborations. The sound of the sea is never far away from events, with local food and drink to the fore. There are talks and outings, concerts and ceilidhs. Venues include a 17th-century country house and a 12th-century cathedral.

5–11 September 2013
www.oisf.org
orkneyscience@gmail.com

Brighton Science Festival

First in the field after the Christmas doldrums every year, Brighton likes to flag up the anniversaries. This year its DNA's 60th, in the company of many other delights – Robin Ince, Ben Goldacre, Belle de Jour, Richard Wiseman, the Festival of the Spoken Nerd, etc – in a month-long feast of serious fun. Mostly the action is over weekends. Go to our capacious website to get a full picture.

6 February–3 March 2013
www.BrightonScience.com
☎ +44 (0) 1273 777628

Energise your mind this September

The perfect guide to further learning in 2013

The Royal Society Summer Science Exhibition

THE ROYAL SOCIETY

With over 20 fascinating interactive exhibits you can try your hand at the science changing our world. Question the scientists themselves about the exciting advances they are working on, from mapping the Big Bang to generating power from the sea to exploring our DNA. This six-day event also features a host of free talks, debates and activities.

royalsociety.org/summer-science
☎ 0207 451 2244

At Bristol - After Hours

@Bristol SCIENCE CENTRE

With hundreds of interactive exhibits, explosive shows and a Planetarium, At-Bristol is one of the UK's most exciting science centres – and it's not just for children! If you're a big kid at heart then After Hours evenings are perfect for a night out with a difference: an intriguing blend of hands-on exploration, inspiring live science, and special themed activities. Put your forensic skills to the test with CSI Harbourside on 11 April; check online for future events.

at-bristol.org.uk/afterhours **☎ 0845 345 1235**

Herstmonceux Astronomy Festival

THE Observatory SCIENCE CENTRE AT HERSTMONCEUX

The annual Astronomy Festival at The Observatory Science Centre, Herstmonceux is packed with activities, including camping under the backdrop of the observatory domes, lectures, amateur radio demonstrations, trade stalls, family fun day, fund-raising raffles, beer tent, telescope tours, planetarium shows and viewing through some of the country's largest telescopes (weather permitting). Come and soak up the incredible atmosphere among the domes and telescopes of this fabulous historic site.

6-8 September 2013
www.the-observatory.org
☎ 01323 832731

The Times Cheltenham Science Festival

THE TIMES CHELTENHAM FESTIVALS SCIENCE13 Pfizer

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4-9 June 2013
cheltenhamfestivals.com
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... at the British Science Festival

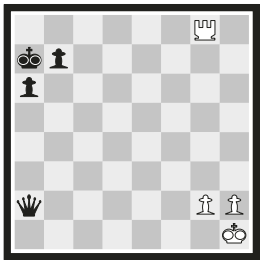
british science festival NEWCASTLE 7-12 SEPT 2013

MINDGAMES

BBC FOUR Pit your wits against these brainteasers by David J Bodycombe, question-setter for BBC Four's *Only Connect*

PRIZE PUZZLE

A spectator may assume the Black Queen will give checkmate here, but actually it's White's move, and she'll win. What move does she make?



WIN! *AFRICA* ON DVD

The first five correct entries win a copy of *Africa* on DVD (BBC, £25)

Post your entry, marked 'Prize Puzzle 252', to: *Focus* magazine, PO Box 501, Leicester, LE94 0AA, to arrive by 5pm on 7 March 2013. We regret that we cannot accept email entries for this competition. See sciencefocus.com/winners for a list of previous winners and solutions.

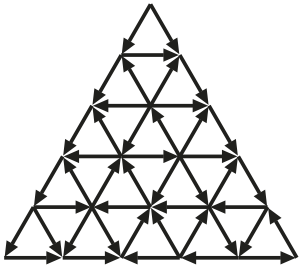
See bottom of p104 for terms and conditions. Congratulations to Janette Leonard (West Lothian), Robert Connell (Norfolk), Hannah McLean (Edinburgh), Andrew Holmes (Northumberland), and RF Tindell, who all answered December's Prize Puzzle correctly and each win a copy of *The Cosmic Tourist*.

Q1

What links the creation of 10-pin bowling, mime artistry and ice cream sundaes?

Q2

Which junction in this network takes longest to get to, if you start from the top corner and always travel in the direction of the arrows?



Q3

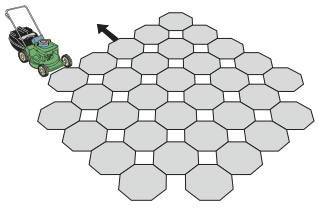
H is to GRAM as D is to... what?

Q4

An estate agent is selling four acres of land for £14,000 or seven acres for £23,000. He makes the same profit on either deal. How much profit would he make on 26 acres?

Q5

Unfortunately, this lawnmower can only move in straight lines or 90-degree left turns. Entering and exiting where shown, what is the lowest number of left turns needed so that each patch is mown at least once?



Q6

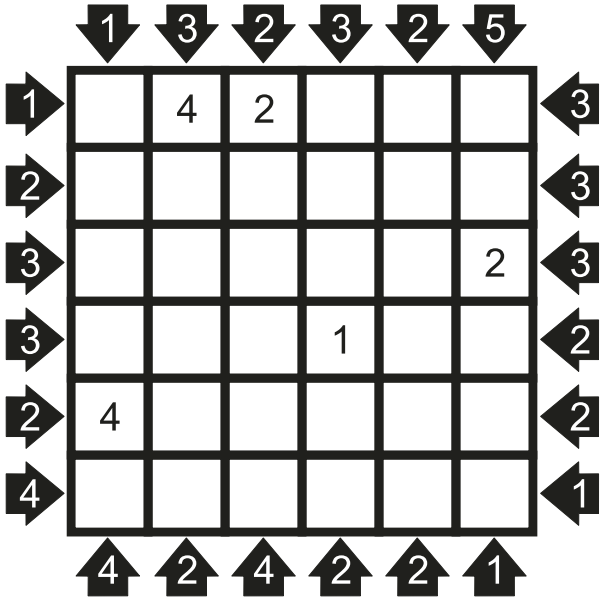
Sally and Peter are standing in opposite corners of the same field. Sally can see the same number of bulls and cows in the field. However, Peter can see twice as many cows as he can bulls. Explain the difference, then deduce how many bulls and cows are in the field.

Q7

What letter is missing from this sequence? YZEPTGMk1m_npfazy

Q8

This 6x6 grid represents the 36 blocks of a city plan. Each row and column contains six skyscrapers of different heights (1 to 6 storeys each). Four building heights have already been marked. The arrows show how many of the skyscrapers a viewer, looking from a long distance away, could see in that row or column – with some shorter buildings impossible to see because they are behind taller ones. Complete the grid.



SOLUTIONS

Q1) They were invented to circumvent bans (on 9-pin bowling, acting performances and ice cream sodas).
Q2) In the row of three triangles, the bottom vertex of the middle triangle.
Q3) RTED, to give the words Histogram and Distorted.
Q4) £12,000. 7A + P = 23 and 4A + P = 14, so (subtracting one equation from the other) 3A = 9 and so one acre costs £3K, meaning profit is £2K per sale. The only way to sell 26 acres is 7+7+3+3+3+3, so these six deals will earn 6x £2K profit.
Q5) 10 turns are required.
Q6) Sally is a cow and Peter is a bull. There are four cows and three bulls in the field.
Q7) The Greek letter mu, to represent 'micro'. These represent the increasing powers of 1,000s (kilo, Mega, Giga, Tera...) and 1/1,000ths (milli, micro, nano, pico...).
Q8) See illustration.

QUICK QUIZ

Test your knowledge of earthquakes

Q1

Roughly how long is the San Andreas Fault?
- a) 1,300km
- b) 1,600km
- c) 1,900km

Q2

In which decade was the Richter scale developed?
- a) 1890s
- b) 1910s
- c) 1930s

Q3

Which of these is not a type of seismic wave?
- a) P-wave
- b) S-wave
- c) U-wave

Q4

Scientists in which country were jailed after the L'Aquila earthquake in 2009?
- a) Spain
- b) Italy
- c) Greece

Q5

Which scale measures the effect of a tremor on the Earth's surface?
- a) Modified Mercalli Intensity Scale
- b) Modified Marconi Intensity Scale
- c) Modified Marinelli Intensity Scale

Q6

How strong was the 'quake that caused the Fukushima nuclear disaster?
- a) Magnitude 7.0
- b) Magnitude 8.0
- c) Magnitude 9.0

Q7

7) In which US state was the 1964 Good Friday Earthquake?
- a) California
- b) Alaska
- c) Nevada

ANSWERS:

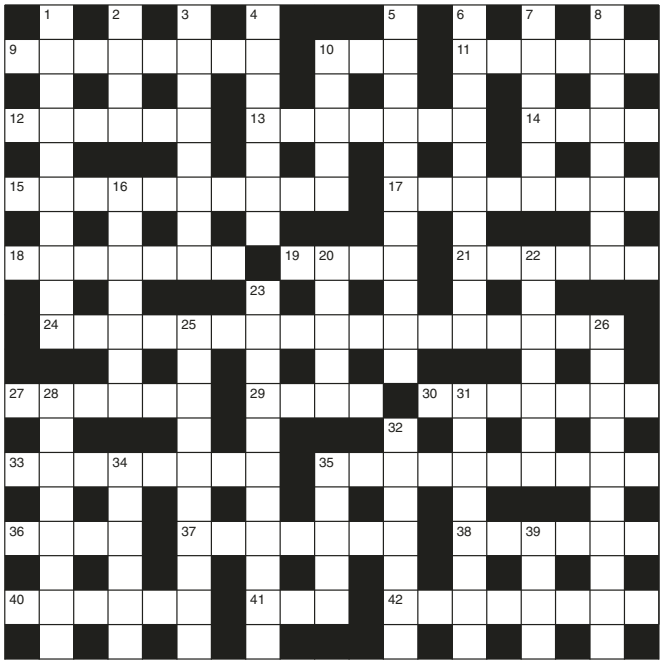
1a, 2c, 3c, 4b, 5a, 6c, 7b

YOU ARE:

0-3 Quaking in your boots
4-5 Shaken but not stirred
6-7 Rockin' all over the world

FOCUS CROSSWORD No 148

EVERY MONTH, A NEW CHALLENGE SET BY AGENT STARLING



ACROSS

9 Copes too awkwardly with instrument (8)
10 Raw material from the forest (3)
11 Father's in Mali, roaming like an antelope (6)
12 Make an effort to find cultural medium (6)
13 Tornado may warp queen (7)
14 Luge fixed with adhesive (4)
15 Point on curve turned into a locus (10)
17 I got in – in to arrange firing system (8)
18 Nitric compound – an additive to a gemstone (7)
19 Lies about some land (4)
21 Laugh at idiot returning as a cleaner (6)
24 Hereditary complaint from unusually-shaped prison room (6-4,7)
27 Braved translation of descriptive word (6)
29 Closely examine part of the skin (4)
30 Catholic has put relative in the frame (7)
33 Relying on working with cold, sweet liquid (8)
35 Best arenas built somewhere in the Arctic (7,3)
36 Food for a youngster (4)
37 Ate nuts when suffering disease (7)
38 Tiny moment (6)
40 We heard him swear at something flashing on-screen (6)
41 Very excited about whisky (3)
42 Check Roy has moved within hearing (8)

DOWN

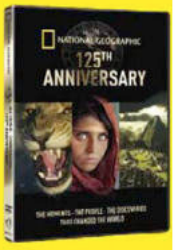
1 Figures it's oddly motionless outside school (10)
2 Doss around Greek mountain (4)
3 Unit of an alternative design of jet (8)
4 Muscle doled it out (7)
5 Let nice part be moved towards the middle (11)
6 I tell acorn about grass (10)
7 Leave skewer round stopper (6)
8 Georgia has a locum treating disease (8)
10 Alternatively charge to see some stars (5)
16 University drip lost king in part of labyrinth (7)
20 Orals devised about a star (5)
22 Only moss is cultivated by diffusion (7)
23 Therapy for a copper getting a blow-out (11)
25 Room for experiment (10)
26 Airy lament about food (10)
28 I'm riled about getting union in confusion (8)
31 Deliver edam, strangely not mass-produced (4-4)
32 Weep at last broken glass (7)
34 Youngster first becomes a painter (6)
35 Buddhist priest is right out of a sculpture (5)
39 Not a new defence group (4)

SOLUTION TO CROSSWORD No 145

Jennie Mallinson, Danny Collins, Philip Cooper, David Cockrell and Lyn Imeson all solved issue 249's puzzle and each win a copy of *Everything You Need To Know About Inventions*.

WIN! A COPY OF *NATIONAL GEOGRAPHIC 125TH ANNIVERSARY* ON DVD

The first five correct solutions drawn will each win a copy of *National Geographic 125th Anniversary* on DVD (£15.99). Entries must be received by 5pm on 7 March 2013. See below for more details.



YOUR DETAILS

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Post entries to *Focus*, March 2013 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to march2013@focuscomps.co.uk by 5pm on 7 March 2013. Entrants must supply name, address and phone number. By entering, participants agree to be bound by the terms & conditions, printed in full on page 104. Immediate Media, publisher of *Focus*, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

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INTO THE FUTURE

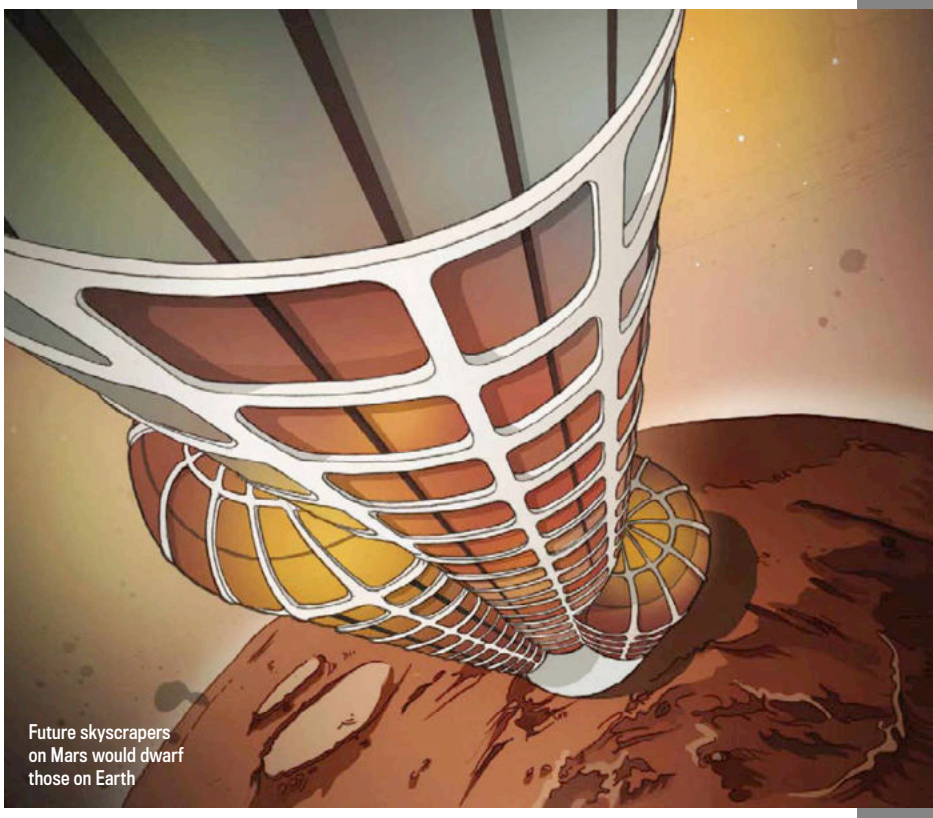
STEPHEN BAXTER

TOM CRUISE CLAMBERS around the outside of Earth's tallest building, Dubai's 828m-high Burj Khalifa, in the film *Mission: Impossible – Ghost Protocol*. Materials available since the 1960s could enable us to build a skyscraper as tall as 4km, but there are practical considerations, such as the room taken by the building's 'footprint' that is the ground area it occupies, and the sheer time it would take to ride an elevator to the top!

Earth's gravity is a basic constraint on height. But one day, perhaps, we will build on other worlds – on Mars, for example, where gravity is only a third of Earth's. How tall could we build skyscrapers there?

We will be constrained by the materials available. Aside from what we import from Earth, there will only be the local stone. But the low gravity will lend a big hand. With materials of the same tensile strength, a structure could be three times taller than on Earth for the same base footprint. Even though the three-times-taller Martian building would have three times the mass of the Earth building, the lower gravity means the two buildings would have the same weight, so the overall pressure on the footprint would be the same. The world's tallest pyramid was 146m tall. On Mars that could rise to 438m.

And if in theory we could build a skyscraper up to 4km on Earth, on Mars the tallest building might reach over 10km. The top floors would be above two-thirds of the Martian atmosphere! Perhaps we could go even higher with more advanced materials.



Future skyscrapers on Mars would dwarf those on Earth

Of course there would be practical constraints. Mars seems to be geologically stable, so earthquakes should not be an issue. Windspeeds can be high but the air is very thin, so the wind would exert little pressure. However, because of that thin air, Mars is more prone to meteorite strikes than Earth; some protection might be needed, such as a weapons system to knock out threatening rocks from the sky.

"If in theory we could build a skyscraper up to 4km on Earth, on Mars the tallest building might reach over 10km."

Why would such buildings be attempted? Perhaps as statements of civic pride, or to drive the development of local industries. And there could be exotic practical uses. In 1992 Richard Taylor of London University proposed 'paraterraforming' Mars. Rather than 'terraforming' Mars – trying to make the whole planet earthlike – you could enclose a great swathe of it under a glass roof, a 'worldhouse', which would be pressurised to contain an Earthlike atmosphere. Taylor imagined support pillars 3km tall; as can be seen from the above arguments, this would be eminently practical.

The tallest 'building' anybody is likely to build on any planet is a 'space elevator'. As described by Bradley C Edwards, co-author of *The Space Elevator* (2003), on Earth you would begin with a satellite in 'geosynchronous orbit', that is orbiting Earth in 24 hours and so hovering over the same spot on the equator. Such an orbit is about 36,000km high. You would drop a cable of super-strong materials down to Earth's surface, and use it as an elevator system. The reduction in cost of getting cargo into space would be huge, but the engineering details are challenging.

Building an elevator on Mars would be easier, because of the lower gravity. On Mars the synchronous orbit is only two-thirds as high as Earth's, so the elevator cable would only need to be two-thirds the length, and the tension in the cable would be reduced too. Perhaps the technology will be pioneered first on Mars, before being brought back to the more challenging environment of Earth.

In the end the reason for erecting tall buildings on Mars, just like on Earth, might simply be for their beauty. To Earthling eyes the towers of Mars would look impossibly tall, impossibly slender, like old science fiction dreams. ■

STEPHEN BAXTER is a science fiction writer whose books include the *Destiny's Child* series and *The Science Of Avatar*

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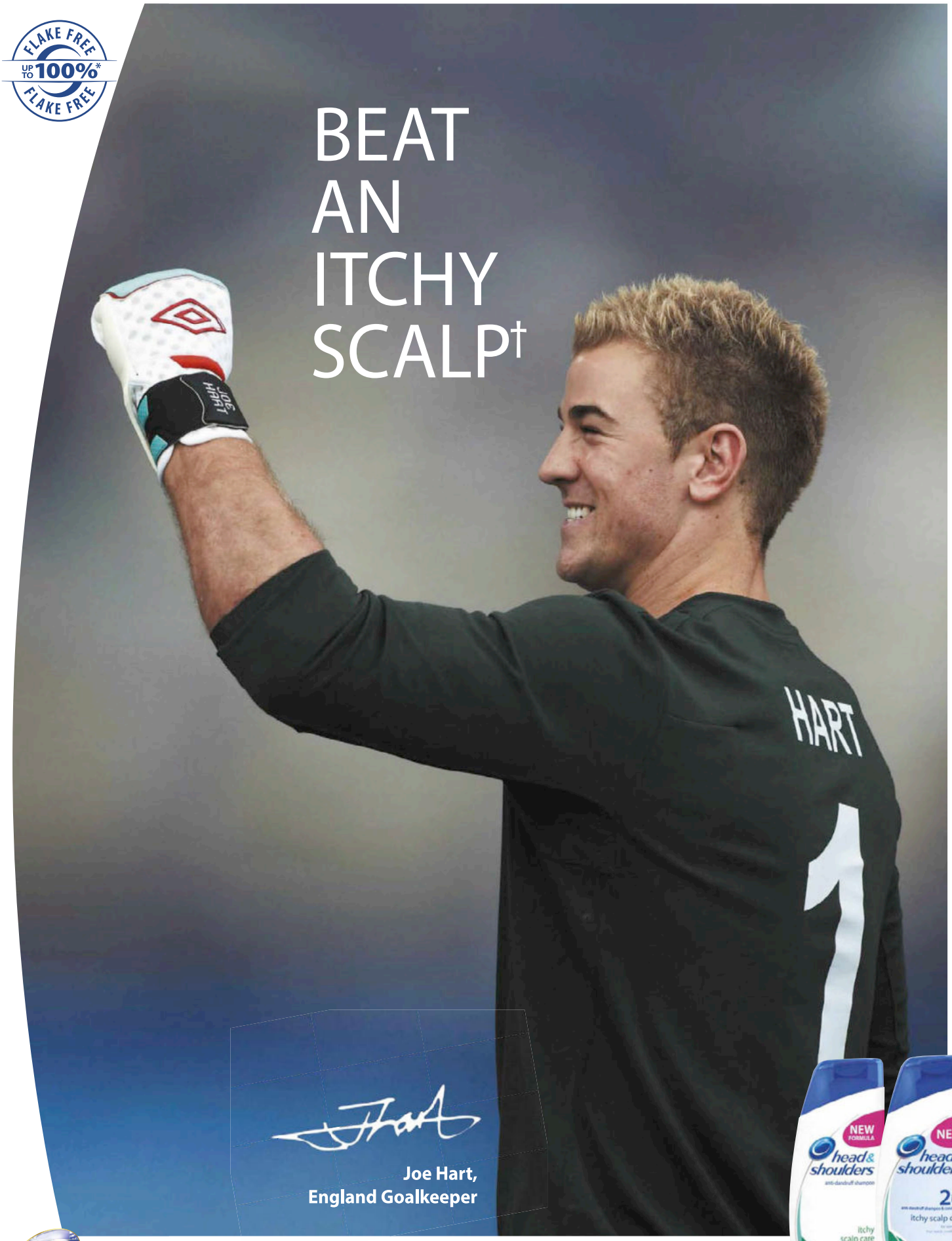

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